Advanced process control
Introduction

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"The goal of my research is to develop simple yet rigorous methods to solve problems of engineering significance"

Course Summary NTNU

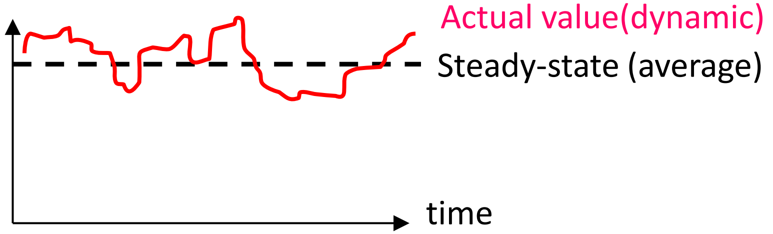
This course is about how to operate and control complete chemical plants

- Part 1: Introduction and motivation
- Part 2 : Plantwide control
- Part 3 : Self-optimizing control
- Part 4 : PID tuning (SIMC rules)
- Part 5 : Inventory control and TPM, Supervisory control and switching
- Part 6 : ARC elements
- Part 7: More on switching and regulatory control
- Part 8: Nonlinear steady-state models: Transformed inputs, RTO and Extremum seeking control.

Part 1: Introduction and motivation

Why do we need control?

- *Operation*



In practice steady state doesn’t happen:

- Feed changes
- Startup
- Operator changes
- Failures
- …..

“Disturbances” (d’s)

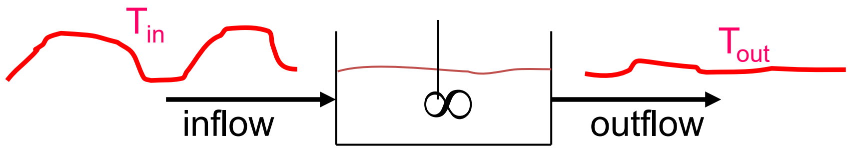
- Control is needed to reduce the effect of **disturbances**
- 30% of investment costs are typically for instrumentation and control

Countermeasures to disturbances

I. Eliminate/reduce the disturbance

(a) Design process so it is insensitive to disturbances

- Example: Use buffer tank to dampen disturbances



(b) Detect and remove source of disturbances

- "Statistical process control"
- Example: Detect and eliminate variations in feed composition

Countermeasures to disturbances

II. Process control

Do something (usually manipulate a valve) to

counteract the **effect** of the disturbance

(a) Manual control: Need operator

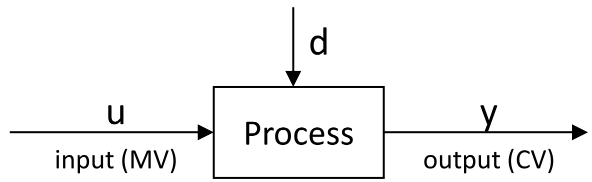
(b) Automatic control: Need measurement + automatic valve + computer

Goals automatic control:

- Smaller variations
  - » more consistent quality
  - » More optimal
- Smaller losses (environment)
- Lower costs
- More production

Industry: Still large potential for improvements!

Classification of variables



Independent variables ("the cause"):

(a) Inputs (MV, u): Variables we can adjust (valves)

(b) Disturbances (DV, d): Variables outside our control

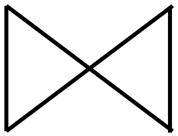
Dependent (output) variables ("the effect or result"):

(c) Primary outputs (CVs, y_1): Variables we want to keep at a given setpoint

(d) Secondary outputs (y_2): Extra measurements that we may use to improve control

Inputs for control (MVs)

- Usually in process control: Inputs (MVs) are valves.
  - Physical input is valve position (z), but we often simplify and say that flowrate (q) is input



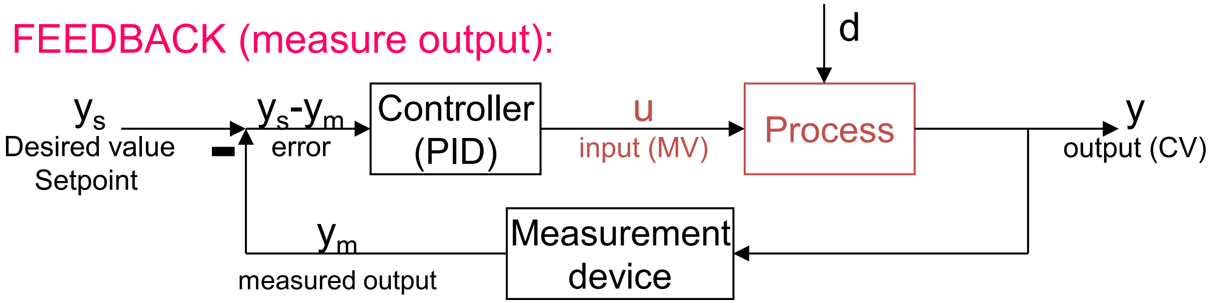
- Valve equation: $q\left(\frac{m^3}{s}\right) = c_v f(z)\sqrt{\Delta p/\rho}$
  - Δp = pressure drop over valve (disturbance; can be counteracted with flow controller)

We use two kind of diagrams

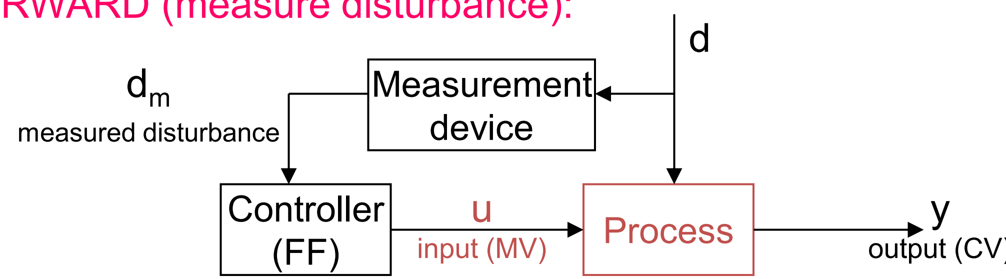
- **Block diagram (information)**
  - Used by control engineers
- **Flowsheet (piping & instrumentation diagram, P&ID)**
  - Used by process engineers

BLOCK DIAGRAMS

FEEDBACK (measure output):



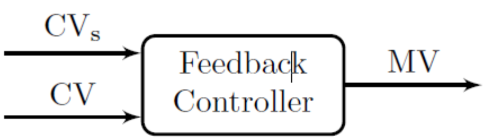
FEEDFORWARD (measure disturbance):



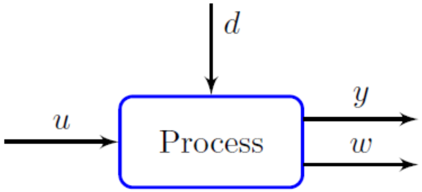
- All lines: Signals (information)
- Blocks: controllers and process
- Do not confuse block diagram (lines are signals) with flowsheet (lines are flows); see below

BLOCK DIAGRAMS

Two DOF feedback controller



MV = manipulated variable (controller output)
CV = controlled variable (controller input)



u = process input (adjustable)
d = disturbance (non-adjustable)
y = process output (with setpoint y_s)
w = extra measured process variable (state x, y_2)

Simple Combination:

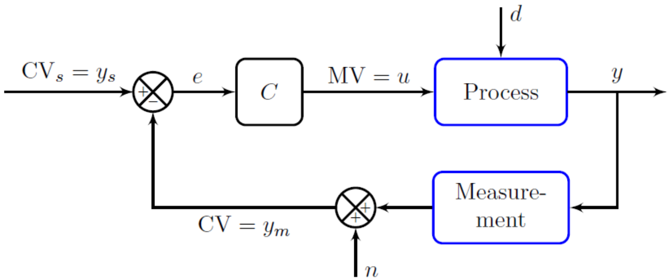


Figure 3: Block diagram of common "one degree-of-freedom" negative feedback control system.

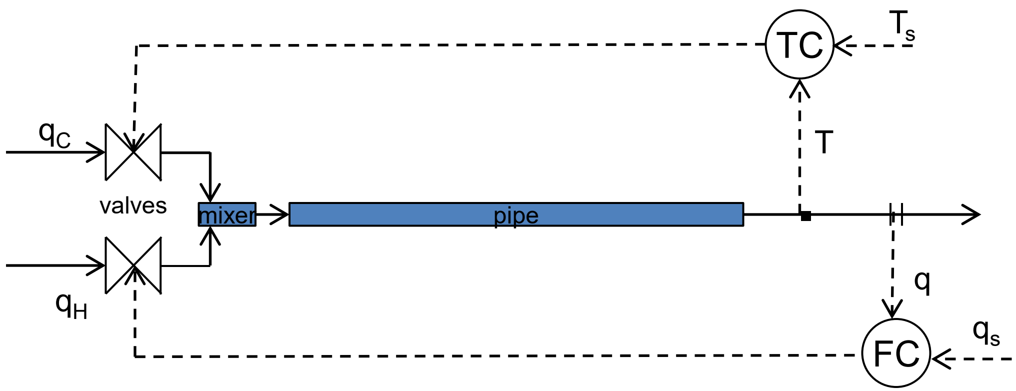
$$e = y_s - y_m$$

Block diagrams: All lines are signals (information)

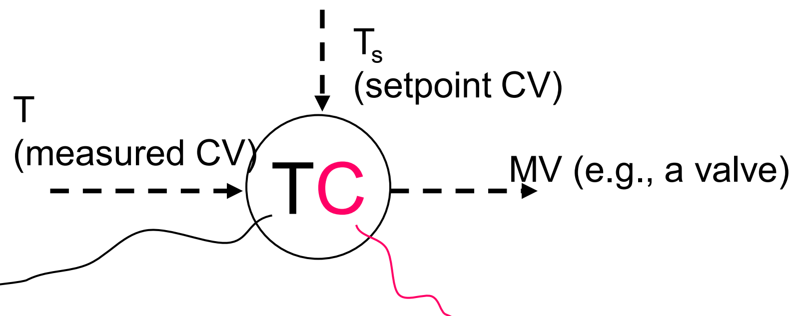
Piping and instrumentation diagram (P&ID) (flowsheet)

- Solid lines: mass flow (streams)
- Dashed/colored lines: signals (control)

Example: Shower



Notation feedback controllers (Flowsheet = P&ID)

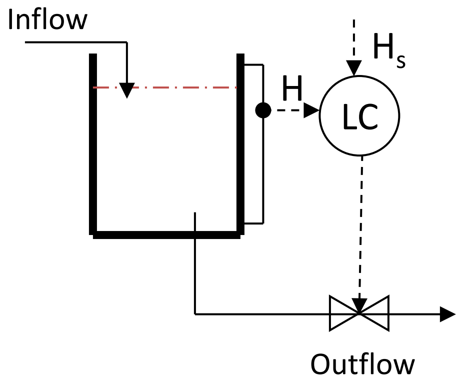


1st letter: Controlled variable (CV)
- **T: temperature**
- **F: flow**
- **L: level**
- **P: pressure**
- DP: differential pressure (Δp)
- A: Analyzer (composition)
- C: composition
- X: quality (composition)
- H: enthalpy/energy

…

2nd letter:
- C: controller
- I: indicator (measurement)
- T: transmitter (measurement)

Example flowsheet: Level control



INPUT (u): OUTFLOW (Input for control!)
OUTPUT (y): LEVEL
DISTURBANCE (d): INFLOW

Scaling

- Variables (u=MV,y=CV,d=DV) are usually scaled
  - Simplifies interpretation and tuning
  - Make sure that valves actually go to fully open or closed
- Linear systems (block diagrams): Variables usually «shifted» with 0 as nominal value, Typical scaled range: -1 to 1
  - where -1 is min. value, 1 is max. value
- Industry (flowsheets): Usually scaled 0-1 or 0-100%.
  - where 0 is min. value (e.g., closed valve)
  - 1 or 100% is max. value (fully open valve)
  - Usually no nominal value