2007
2008

INTRODUCTION TO PROCESS CONTROL

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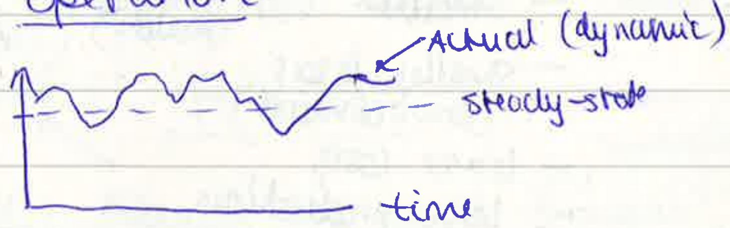
Why control?

Until now: Design of processes. Assume steady-state

Here: Operation.



In practice, never steady-state

- Feed changes
- Startup / shutdown
- Failures

} "Disturbances" (d)

~~To minimize~~

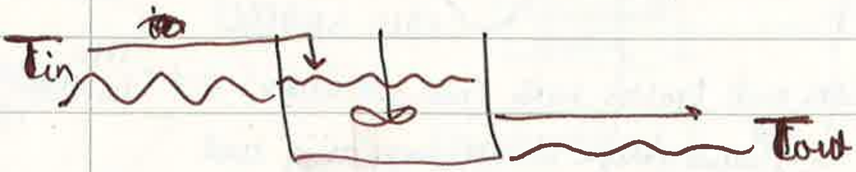
- Control is needed to reduce the effect of ~~disturbances~~ d's
- 30% of investment costs are typically for instrumentation and control

Countermeasures disturbances (d's)

I. Preventive measures

a) Detect and remove ~~disturbances~~ d's
"statistical process control" (SPC)

b) Design a process which is insensitive to ~~disturbances~~ d's
Example: Buffertank to dampen disturbances.



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II. Process control ("Prosessregulering")

← manipulate valve

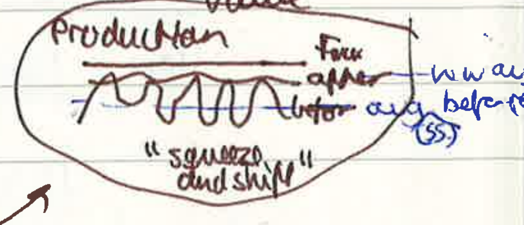
- ~~Counteract the~~ Do something ( ) to counteract the effect of d's.

(a) Manual control : Need operator

(b) Automatic control : Computer + measurements + automatic valve

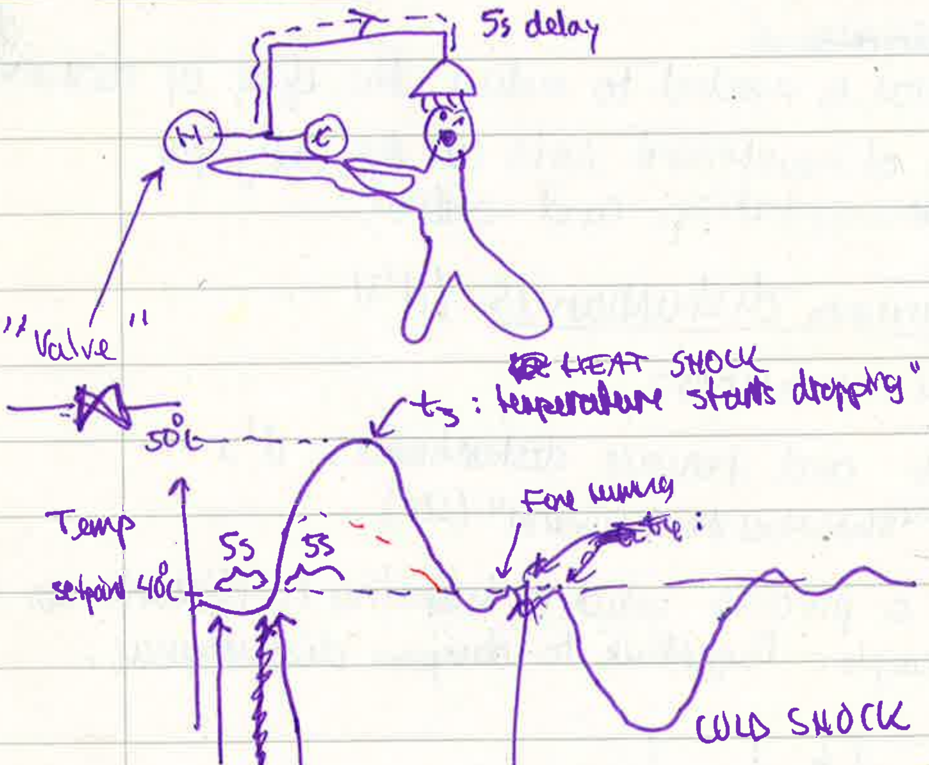
HERE

~~Object~~ Goals:
- less ~~smaller~~ variations (quality)
- smaller losses (environment)
- lower costs
- larger production



Industry: Still large potential for improvements!!

Example. Control of shower temperature



t_1: Room mate brushes teeth (uses cold water) ← THE DISTURBANCES (d)

t_2: Temperature starts increasing and we increase cold water ($=t_1+5s$)

t_4: Room mate finished

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Countermeasures

I) (a) Get rid of room mate ($)

(b) Get own water supply ($)

II Improved control to get faster response

- Faster response
- ~~Shorter pip~~ is still not OK: Smaller pipe (D smaller) with shorter delay.

Two ~~main~~ fundamental control principles

1) Feedback: Measure the result (output y, ~~temperature T~~) controlled variable CV

and adjust ~~manipulated variable (MV~~ the ~~countermeasure independent~~ manipulated variable (MV, input u, ~~...~~)

until the result is OK

Example: Measure the temperature T adjust the cold water

2) Feedforward: Measure the ~~distur~~ cause (disturbance, DV) d

and ~~predict (model!) its effect on the result~~

~~and~~ based on a prediction (model!) ~~of its effect~~,

make a "forward" adjustment of the MV (input u) to

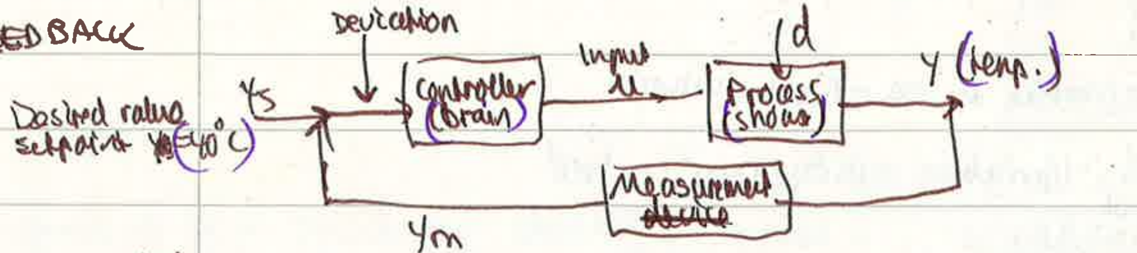
(hopefully) counteract its effect on the result (output y)

Example: Room mate says: "I am tapping cold water" and you ~~reduce your cold~~ ~~increase~~ open ~~the~~ your cold water (by exactly the right amount)

2008: simplified

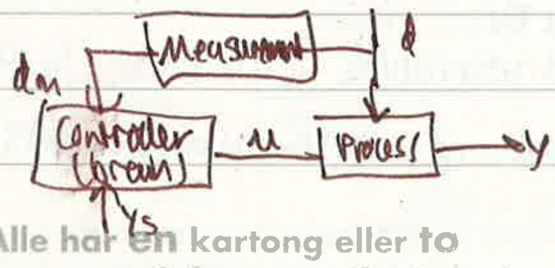
BLOCK DIAGRAMS (information diagrams, signals (not mass flows)).

FEEDBACK



Controller: "Large deviation gives large input change" (SIMPLE)

FEED FORWARD



Controller: Need to think carefully (NEED GOOD MODEL)

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P 1. time 2008

Feedback

+ self-correcting
+ Do not need good model (but must know sign)
÷ May give instability ( ) if ~~you~~ controller overreacts
÷ Need ^fast^ measurement of the output (y_m) -

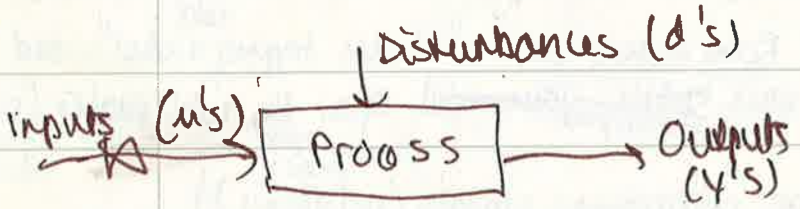
MAIN ENEMY OF FEEDBACK: TIME DELAY!

Feedforward

+ Good ~~when the process have~~ ^with large^ delays
+ React before the damage is done
÷ Need good model
÷ Sensitive to changes
÷ ~~Need meas~~ ^Works^ only for known disturbances
• Usually combined with feedback

1. time ↑ 2007

CLASSIFICATION OF VARIABLES



Not always obvious!

Indep. variables

(a) ~~Manipulated~~ (u) MV's : variables we can adjust (values)

(b) DV's (d) : Variables outside our control

Dependent ^output^ variables

Depend on MV's and DVs.

(a) Primary controlled variables, CV's (y). (with given setpoint y_s)

(b) Secondary outputs, y' : Extra measurements

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Idea control system:

- Based on measurements (y_m, y_m', d_m) use the manipulated variables (u) to counteract the disturbances (d) such that the output is kept at it's setpoint ($y \approx y_s$)

Controller: Algorithm for how this is done

Here: ~~...~~ Focus on the structure: Which variables?
(This is the most important!)

Example shower (continued)

MV's (u's): q_C and q_H [m^3/s]
(cold water, hot water)

DVs (d's): T_C, T_H + undesirable changes in q_C and q_H (due to pressure variations)

Primary Outputs (CVs): T and q (total flow)
~~often called~~ "pressure" of the flow

single loop control:

~~Alt.1.~~ Pairing 1
$q_C \leftrightarrow T$ (use q_C to keep $T \approx T_s$)
$q_H \leftrightarrow q$

Alt. 2 (pairing 2)
$q_H \leftrightarrow T$
$q_C \leftrightarrow q$

Alt. 3 "multivariable control"

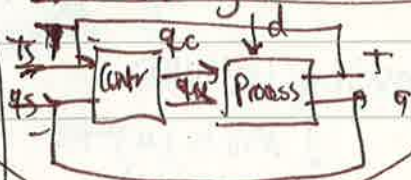
$q_C \leftrightarrow T_C$
$q_H \leftrightarrow T_H$

Example: Modern "mixing battery":
$q_H/q_C \leftrightarrow T$
$q_H + q_C \leftrightarrow q$

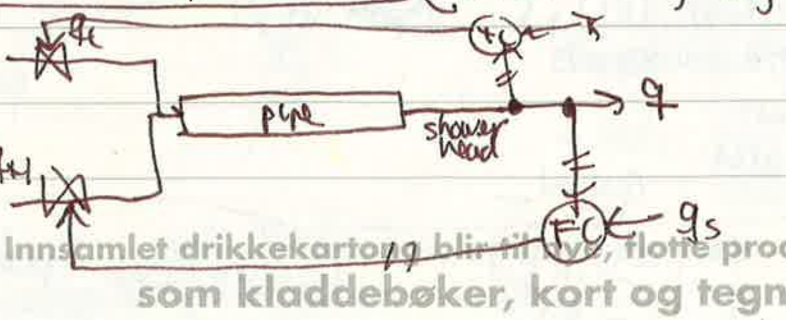
see exam 0 (2005)

Control structure feedback

Block diagram shower (signals)



Process flow sheet for shower (streams —, signals --- or -//-)



• ← meas. point

(TC) = temperature controller

(FC) = flow controller

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TC — 2nd. letter:
C : controller
I : indicator (~~ ~~ measurement)

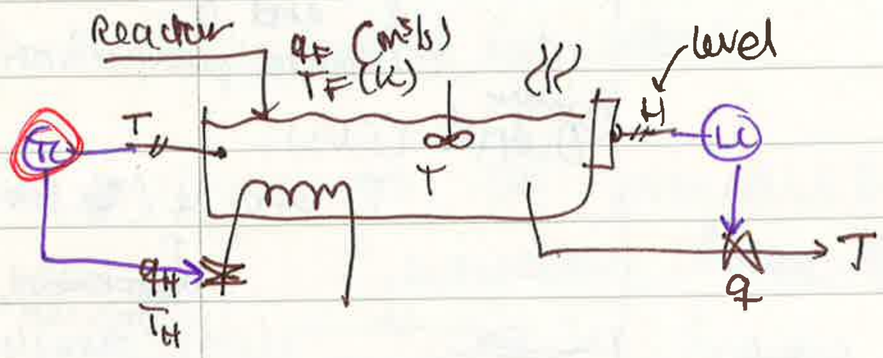
1.st letter: What we are trying to keep constant
T : temperature
F : flow
L : level
C : composition
P : pressure
DP : ~~pressure~~ differential pressure (Δp)

IN HERE: Procedure for design of control system — ark (1-1)

↑ ~~IN HERE: Example 2 (i) Problem statement (...)~~
2.time: ~~Ferdig med 1.ark (1-3)~~

Example 2. — Ark 1-3

~~Buffer tank~~ with heating
Evaporator
Reactor



1. Objective: keep level (H) ≈ konstant
   keep temp. (T) ≈ konstant (T_s)

2. Classify variables

{ MV's (u) ~~X~~ — q_H, q
{ DV's (d) — q_F, T_F + T_H ... (concentrate on important)

{ Outputs CVs (y) — ~~T,H~~ H, T
{ ~~ ~~ Measurements
↑here

↑ 2. time 2008

3. Process matrix

		Output H	T
Input (MV)	q_H	≈0	+
	q	−	≈0

obvious "pairing" — Ark 1-2

↑ 2. time

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Lecture 3

Most common control structure: "Single-loop" control

$T \rightarrow (TC) \rightarrow q_H$ (Rules for pairing in here)

Other common ones: (MV is setpoint for another controller)

2. Cascade control: Used when we have extra measurements y_m'

3. Ratio control (special simple case of feedforward)

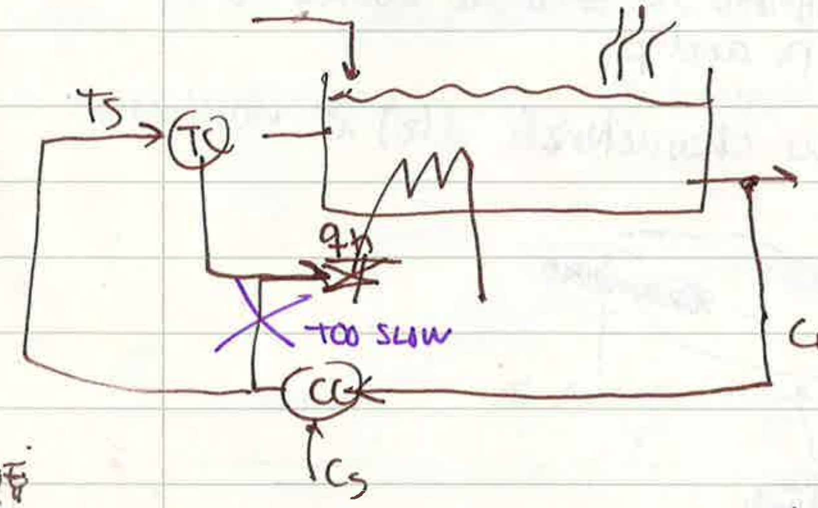
(A) Cascade control

Example 2 continue

- primary objective: Control composition ($Y = C$), of concentrate
  but measurement delayed

Ark 1-3f

- ~~Use extra temperature measurement~~ ~~(as indicator of C)~~
- control temperature in inner loop ($Y' = T$)



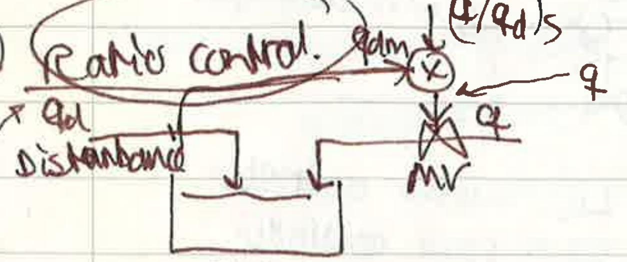
"SLAVE LOOP" → (A) Fast inner temperature loop that keep $T \approx T_s$ ($Y' \approx Y_s'$)

"MASTER LOOP" → (B) Slower outer loop that adjust setpoint in the inner loop: CV = T, MV = q_h

$CV = Y$ (C)

$MV = Y_s'$ (T_s)

(B) Ratio control.



- Want the ratio q/q_d constant
- Have measurement of q_d
- (X): multiplication block
- Note: May adjust $(q/q_d)_s$ in ~~outer~~ slower outer feedback loop (cascade)

Most simple and best feedforward controller?

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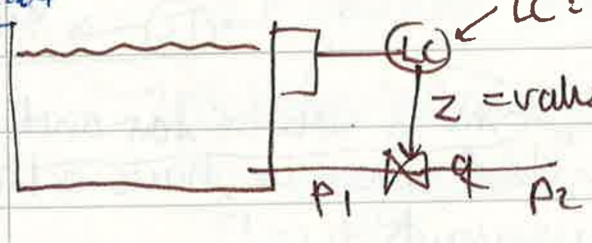
Exercise in here! ← or maybe later

Cascade control is often used on valves (flow control)

Without cascade



Actual flow

$$q = C_v f(z) \sqrt{p_1 - p_2}$$

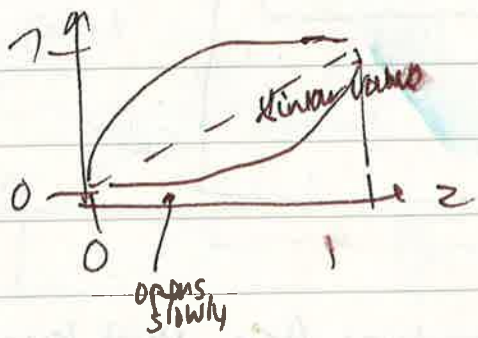
valve coefficient

Problem

~~1) q changes when p_2 changes~~

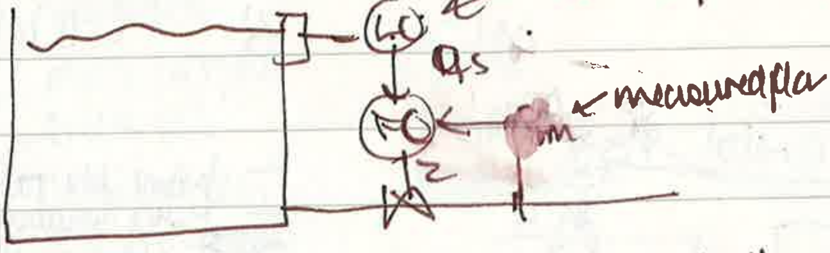
1) q is affected by ~~changes~~ disturbances in p_1 and p_2

2) Valve characteristic $f(z)$ is nonlinear.



Solution! Introduce "inner" flow controller (Would also solve shower problem!!)

With cascade:



LC: master controller

FC: slave controller

3. time 2008

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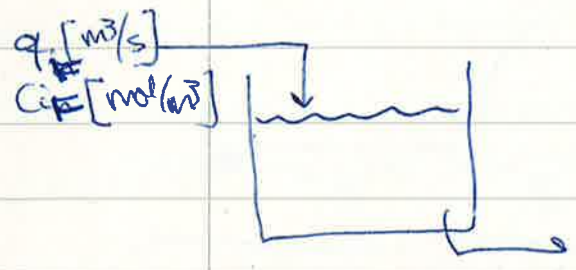
Process Dynamics

- "Things take time"
- Time constant τ [s]

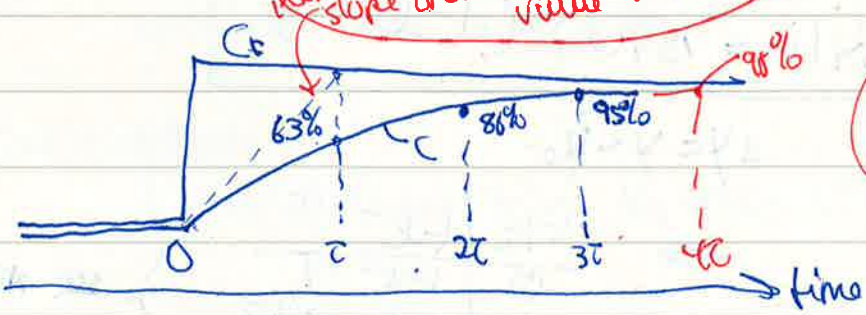
Example. Concentration change in tank



$q \approx q_F$ (assume V [m³] konst.)
$c \neq c_F$ dynamically

Initially ($t=0$): steady-state $\Rightarrow c = c_F$

At $t=0$: Step increase in c_F. What happens?



Note: $1-e^{-1} = 0.63$
$1-e^{-2} = 0.86$
etc

τ = time ~~where~~ for 63% of change

~~Start~~ Derivation: Use balance equation
~~Material~~

$$\frac{d}{dt}(\text{Inventory}) = \text{In} - \text{Out}$$

Here: Component balance

Inventory $= c \cdot V$ [mol]
In $= q \cdot c_F$ [mol/s]
Out $= q \cdot c$ [mol/s]

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$$\frac{d}{dt}(c \cdot V) = q\, c_F - q \cdot c$$

constant volume

$$\frac{dc}{dt} = -\frac{q}{V} \cdot c + \frac{q}{V} \cdot c_F$$

On standard form ~~for~~ 1st order system

$$\boxed{\frac{dy}{dt} = -\frac{y}{\tau} + b}$$

Here:

$y = c$

$\tau = \frac{V}{q}$ (residence time)

$b = \frac{q}{V} \cdot c_F$

General solution

$$\boxed{\Delta y(t) = \Delta y(\infty)\left(1 - e^{-t/\tau}\right)}$$

$\Delta y = y - y_0$

t/τ	$1-e^{-t/\tau}$
0	$1-e^0 = 1$
1	$1-e^{-1} = 0.63$
2	$1-e^{-2} = 0.86$
3	0.95
4	0.98

see ARK

End ~~proof~~ derivation

Other examples: Temperature response in tank

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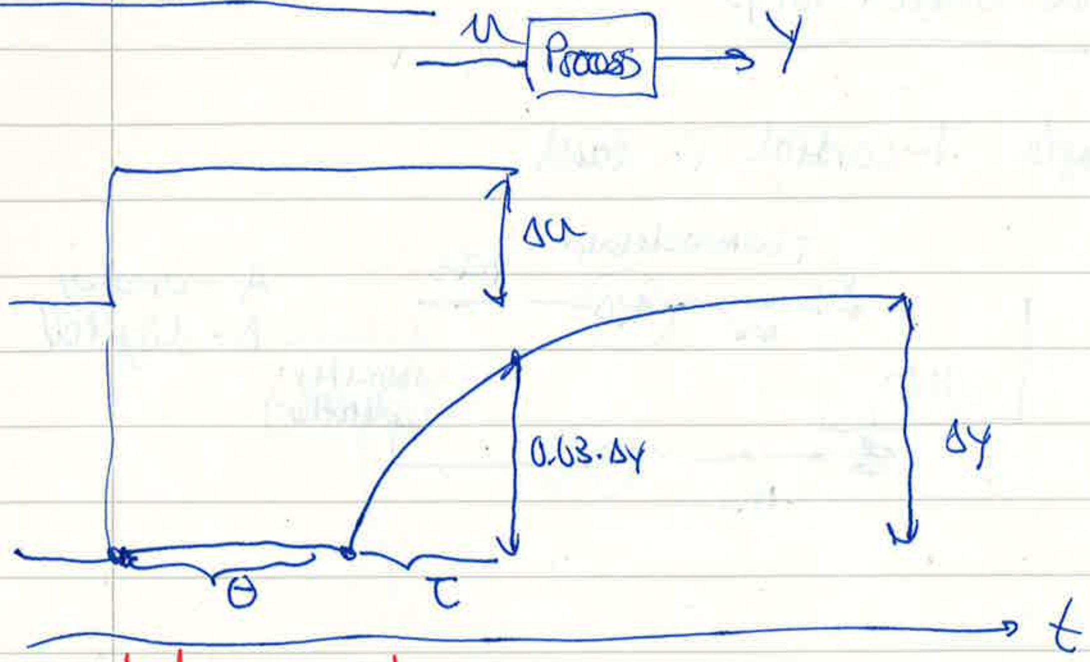
Summary step response



Three important parameters

1. Process gain:
$$k = \frac{\Delta y(\infty)}{\Delta u}$$

2. Process delay
θ = time until y "takes off" in right direction

3. Time constant
τ = Additional time to reach 63% of change

$$\Delta y(\theta + \tau) = 0{,}63 \cdot \Delta y(\infty)$$

For good control we want

1. k large ("sensitive")
2. τ ~~[illegible]~~ small ("responsive")
3. θ small ("direct effect")

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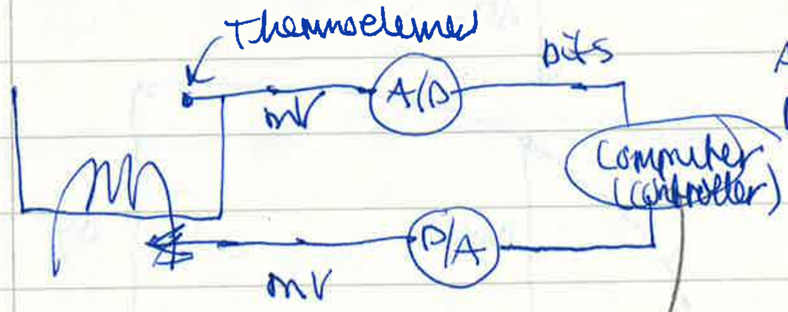
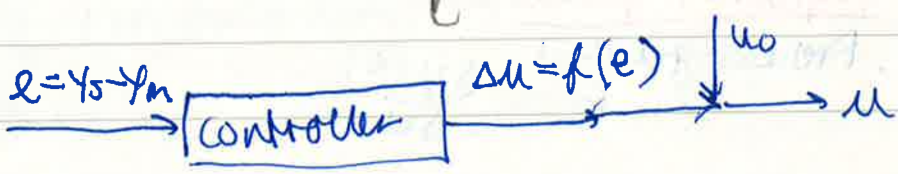
The control loop

example T-control in tank



A - analog
D - digital



simplest: proportional control

$$\cancel{u = u_0 + K_c e}$$

$$\Delta u = K_c \cdot e$$

PID control

$$\Delta u = \underbrace{K_c e}_{P} + \underbrace{K_c \cdot \frac{1}{\tau_I} \int_0^t e(t)\,dt}_{I} + \underbrace{K_c \tau_D \frac{de}{dt}}_{D}$$

Three parameters

K_c - gain

τ_I - integral time (start with large!)

τ_D - der. time (usually zero)

See slides ~~(SIMC)~~ for tuning

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