Lessons Learned during 50 Years in Control

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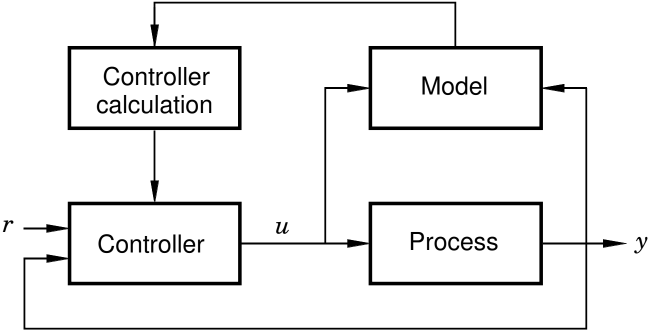
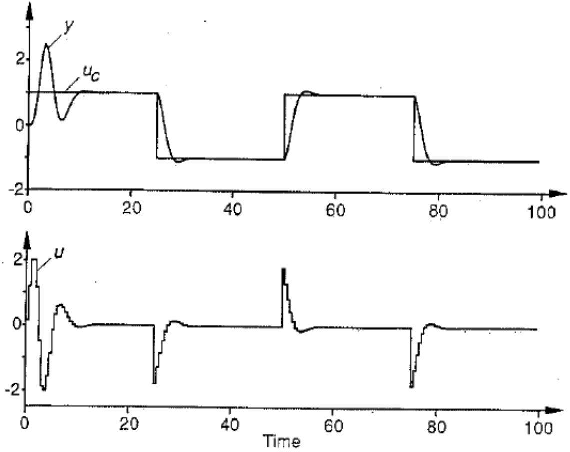
50 years in control

1974 – 1978	Master studies – Lund University
1978 – 1984	PhD studies – Lund University
1985 – 1989	ABB – Lund!
1990 –	Lund University

The adaptive control era



Simulation results



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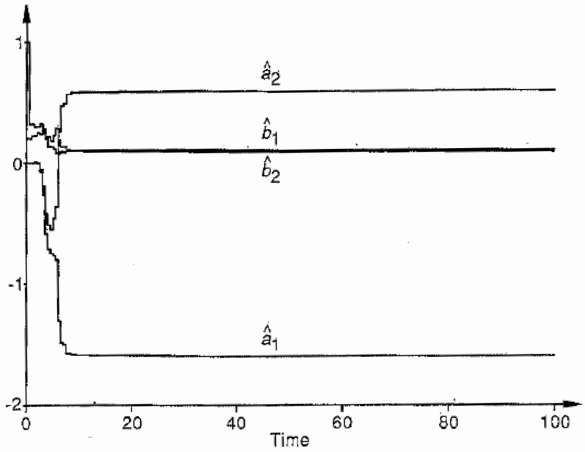
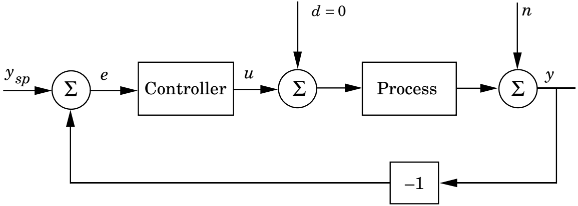


ABB Novatune

This is the final solution

The end of control research

Why did it go wrong?



- Initialization of the controller nontrivial.
- Sampling interval a crucial choice.
- Manual tuning adjustment impossible.
- One must only adapt during excitation.
- Excitation is not always step changes in set point.
- Load disturbances cause desinformation.
- Friction in pumps or valves causes oscillations and detuning.

Lessons learned

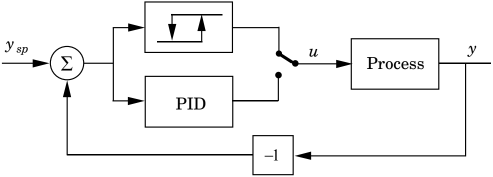
Prerequisites for academic research to reach industrial use:

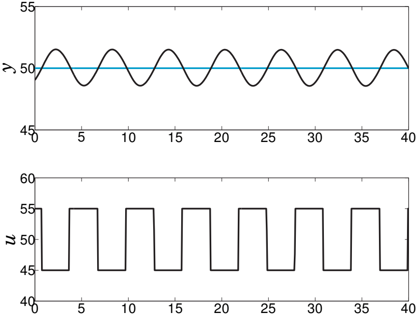
- The research must be done in close contact with industrial people at apropriate levels.
- Simulations are a good start, but must be followed by extensive industrial field tests.

Automatic tuning

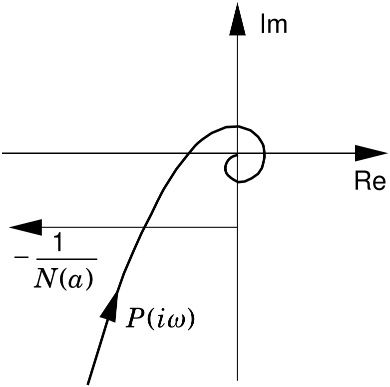
1. Contact with NAF Controls (later SattControl, ABB).
2. Would like to keep the PID controllers.
3. Use adaptive technique to tune the PID controllers.

The relay method





Describing function analysis

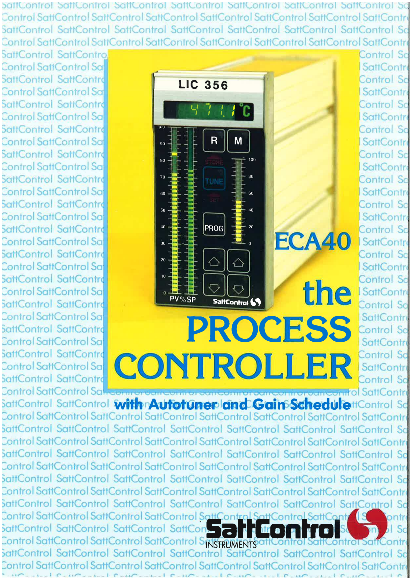


Simple process model, valid in the most important frequency range, obtained automatically without prior information.

SattControl ECA40

SattControl-ECA-40-0000-Temperature-Control-Module... https://usedindustrialparts.com/cdn/shop/files/SattContr...

SattControl ECA40



Automatic tuning

Video!

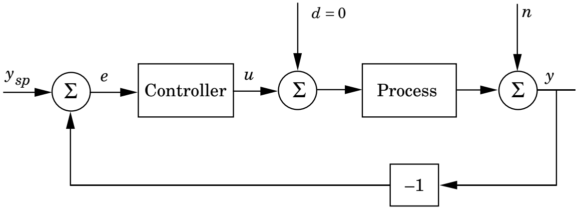
Lessons learned

- Successful project because of the close collaboration between academia and industry, both instrument suppliers and end users.
- We were wrong so many times. Wanted something advanced. They wanted something simple. They new the operators and end users.

Adaptive PID control

- Employed by NAF Controls to develop an adaptive controller.
- Other duties:
  - Develop and give course in process control.
  - Participate in “trouble shooting”.
  - Participate in customer support projects.

Why did it go wrong?



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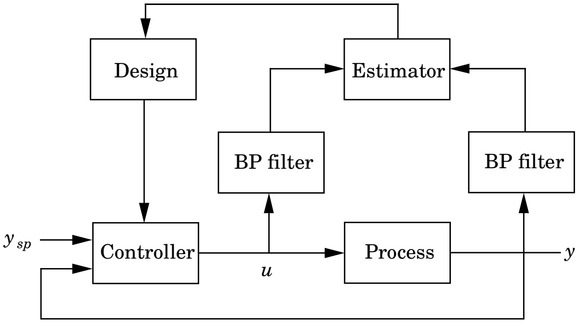
An Adaptive PID controller

Idea:

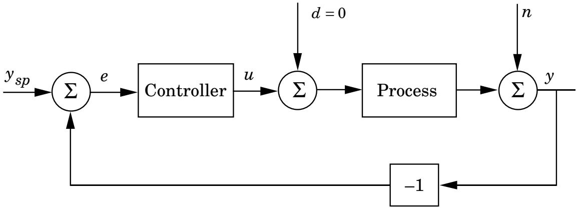
- Keep the PID structure.
- Initialize the controller using the autotuner.
- Track the frequency point identified by the autotuner.

An Adaptive PID controller



Design: Use the controller to place the frequency point on a desired position.

Remaining tasks



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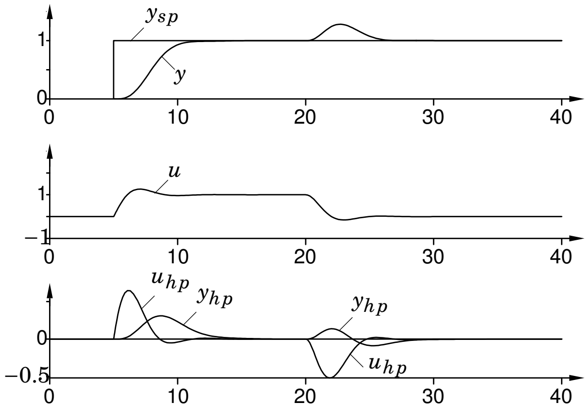
Excitation and load disturbance detection



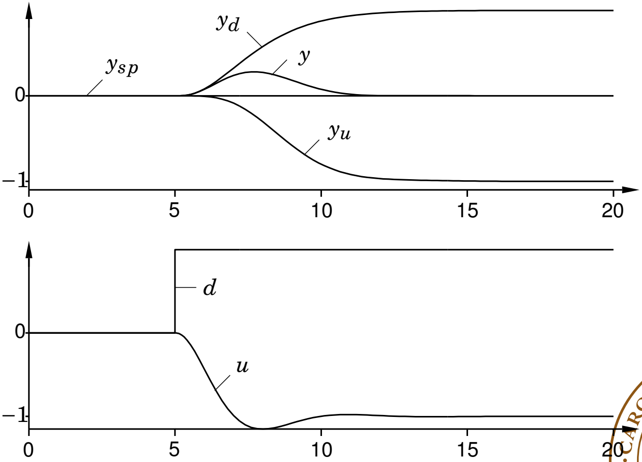
Estimate when $|y_{hp}|$ is large

Set-point changes: $|y_{hp}|$ and $|u_{hp}|$ large, move in the same direction

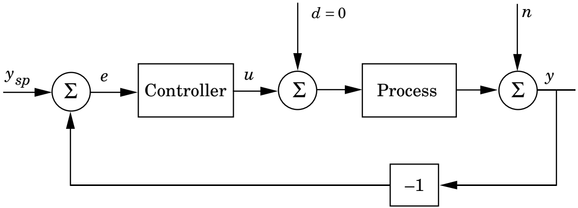
Load disturbances: $|y_{hp}|$ and $|u_{hp}|$ large, move in opposite direction

Problems with load disturbances

Solution: Avoid adaptation when y_d dominates over y_u.



Remaining task



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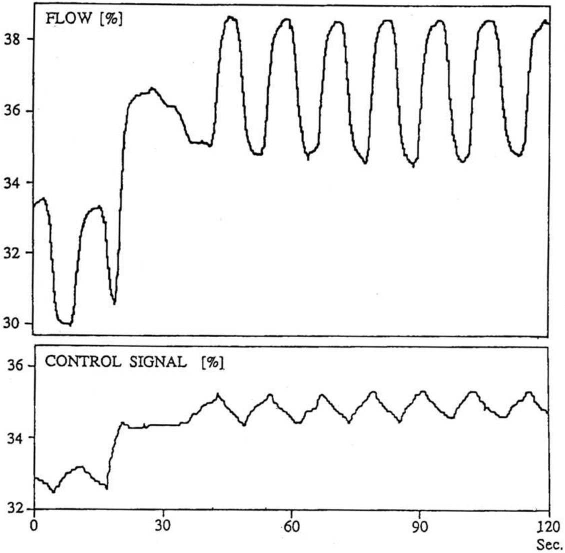
Friction in valves



Oscillation detection

Calculate

$$IAE = \int_{t_{i-1}}^{t_i} |e(t)| dt$$

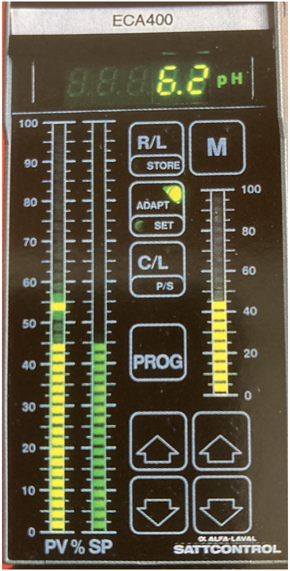
between zero crossings of the control error.

Good control: Small IAE values.

Oscillations: The rate of large IAE values becomes high.

Avoid adaptation when the loop is oscillating!

SattControl ECA400



Stiction and backlash in control valves

Paper-mill audit: About 30% of all control loops suffer from these problems.

“The single most important cause of process variability in process control.”

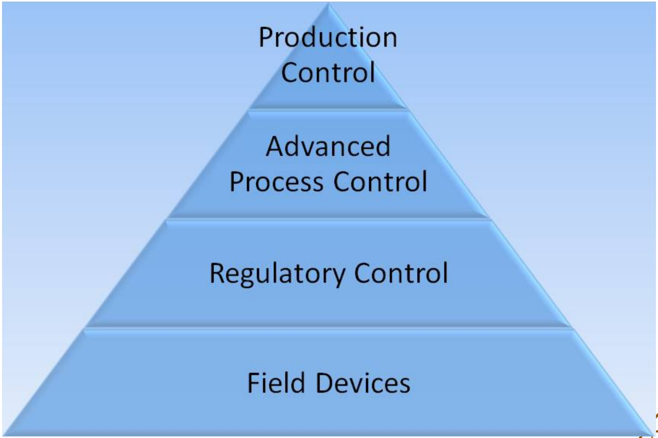
Human supervision in process control

We need automatic performance monitoring!

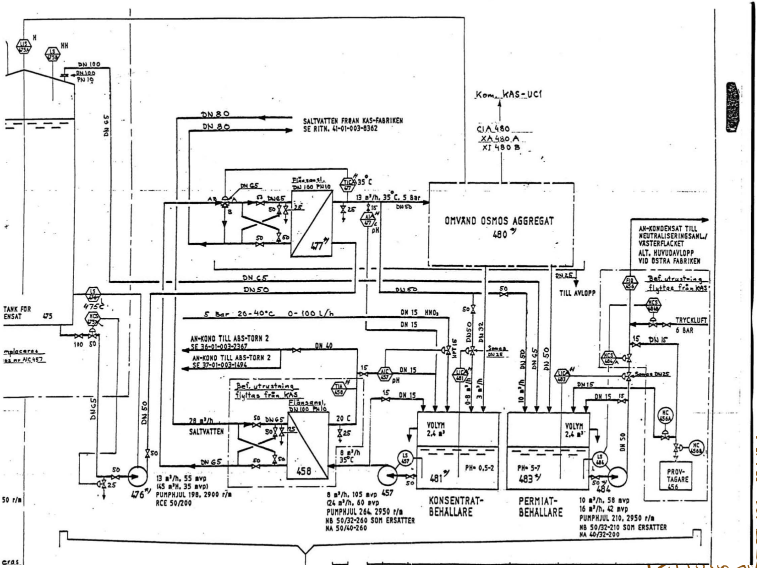
Lessons learned

- Research – Treated most complicated topics first.
- Order of complexity:
  1. Adaptive high-order controller
  2. Adaptive PID controller
  3. Automatic tuning
  4. Supervision and detection
- Security nets around control functions.
  - Important
  - Interesting research projects

Control strategies



A small process section



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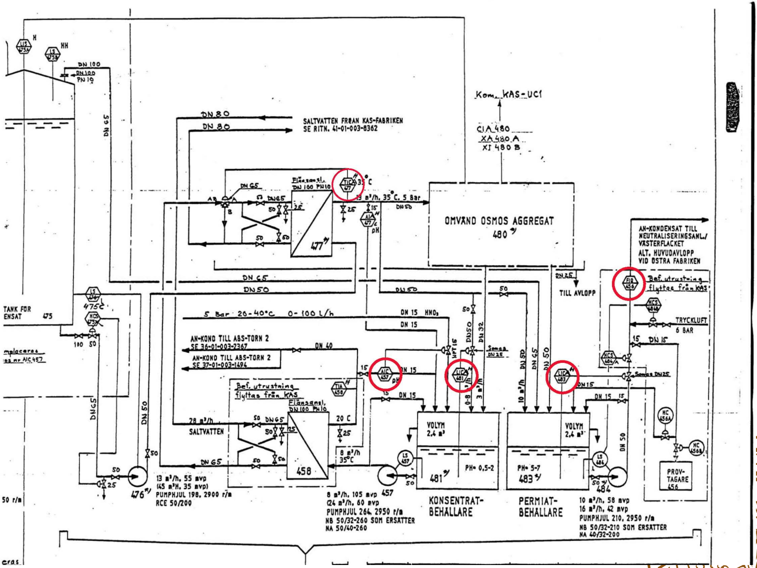


Basic control strategies

Cascade control

Selector control

Mid-range control

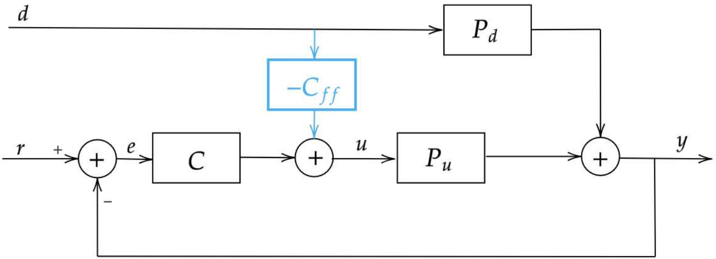
Split-range control

Ratio control

Decoupling

Feedforward control

Feedforward control

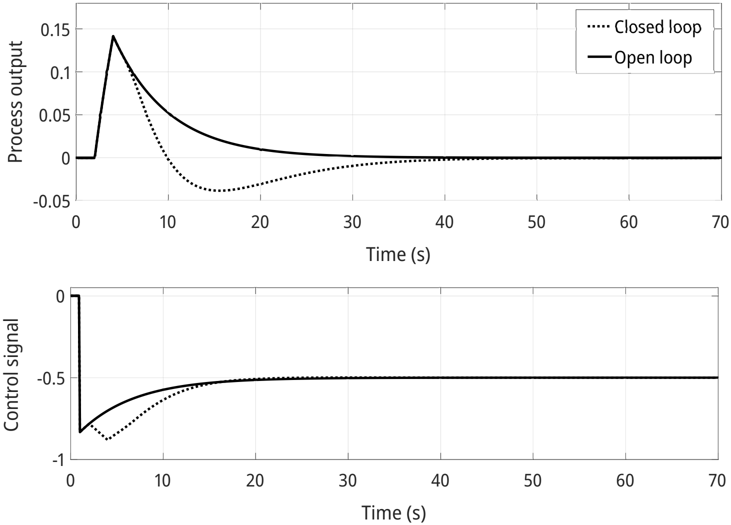


Ideal feedforward control: $C_{ff} = \dfrac{P_d}{P_u}$

Not always realizable!

May be noncausal, nonproper, unstable!

Example – Delay inversion problem



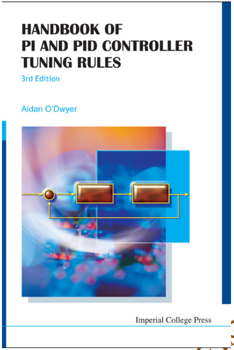
Tuning rules for feedforward controllers

Take feedback controller C into account when designing C_{ff}

Tuning rules for PID controllers: $\sim$ 2000

Tuning rules for FF controllers 2010: 0

Tuning rules for FF controllers 2024: $\sim$ 15



Tuning rules – Example

$$P_u = \frac{1}{1+10s}e^{-3s} \qquad P_d = \frac{0.5}{1+6s}e^{-s}$$

$$C_{ff}^{\text{Ideal}} = \frac{P_d}{P_u} = 0.5\frac{1+10s}{1+6s}e^{2s}$$

$$C_{ff}^{\text{Ignore}} = 0.5\frac{1+10s}{1+6s}$$

Tuning rule to minimize IAE:

$$k_{ff} = \frac{K_d}{K_u}\cdot\frac{T_d+L_d}{T_d+L_u} = 0.5\frac{6+1}{6+3} = 0.39$$

$$C_{ff}^{\text{Tuned}} = 0.39\frac{1+10s}{1+6s}$$

Tuning rules – Example

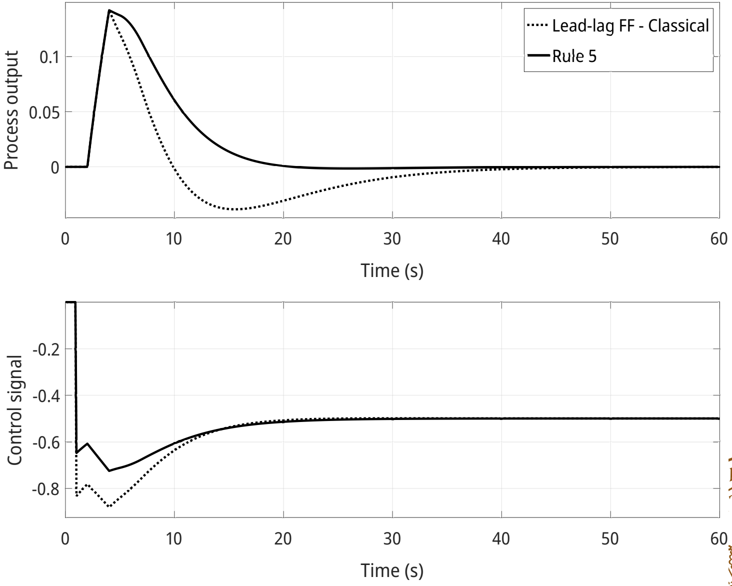


ABB ECA 600 – Adaptive feedforward

Video!

Lessons learned

- Classic control strategies
  - Often used as in the analog time
  - Improvements can be made
- New PID-based control strategies can be developed
  - Mid-range control
  - Ratio control
- People in industry understand and can handle the PID-based strategies

The eighties – The computerization era

- Analog controllers replaced by digital
- PLC systems came
- DCS systems came

The Computerization

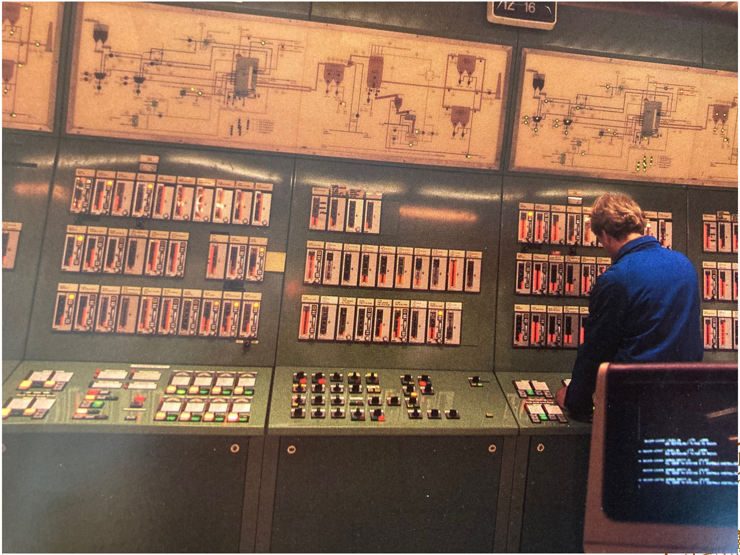
The PID controller has gone through several technology shifts: Pneumatic, analog electric, computer based.

Technology shifts often abrupt and unplanned

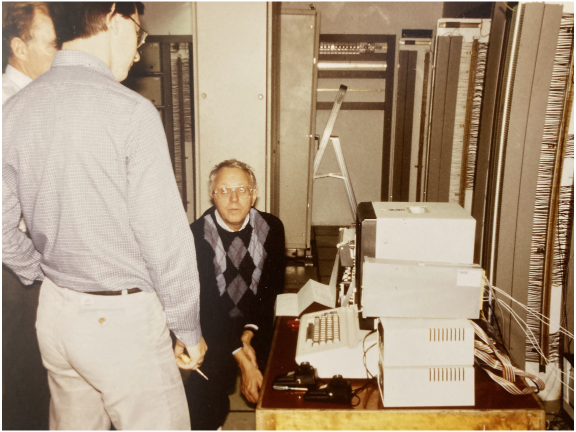
- Old solutions copied.
- Also good time to introduce new ideas.
- Employed new people at R&D department.
- Young people with computer knowledge, but without experience and process control knowledge.
- Experienced people left. Things were forgotten.

DCS system from the 80ies

Control room from the 80ies



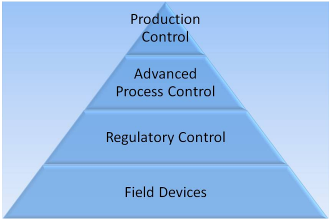
Autotuner field tests at sugar refinary in Arlöv 1982



Autotuner field tests at sugar refinary in Arlöv 1982

Summary – Main lessons learned

- Collaboration with industry important
  - People at right positions
  - Field tests crucial
- Don't forget the security nets
- Don't forget humans in the loop
- Lower levels must be in good shape



Process industries have bad tires!

Lot's of fun improvements to make!