Automatic Control in Sweden

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Lectures

		1940	1960	2000
1	Introduction			
2	Governors	|	|	|
3	Process Control	|	|	|
4	Feedback Amplifiers	|	|	|
5	Harry Nyquist	|	|	|
6	Aerospace	|	|	|
7	Automatic Control Emerges	←	|	|
8	The Second Phase	←	←	|
9	Automatic Control in Sweden	|	|	|
10	Automatic Control in Lund		|	|
11	The Future of Control			→

Automatic Control in Sweden

1. Introduction
2. Power Systems and ASEA
3. Process Control
4. Defense Projects
5. Academia
6. Summary

Theme: Followed the international pattern.

Some Industries

- ASEA (⇒ ABB)
- Ericsson, AGA, Philips, Kockums, Volvo
- Bofors (⇒ Saab ⇒)
- Saab many different companies
- Nordiska Armaturfabriken (NAF ⇒ Saab ⇒ Alfa Laval Automation ⇒ ABB)
- TA (Tour Andersson ⇒ TAC ⇒ Schneider)
- Källe Regulator
- Billman Regulator (⇒ Landis and Gyr ⇒ Siemens)
- Alfa Laval Automation (⇒ Satt ⇒ ABB)
- ElektronLund (Satt Control ⇒ ABB)

Teknologföreningen and IVA

- Svenska Teknologföreningen (Sveriges Ingenjörer, Association of Swedish Graduate Engineers)
  - The Club Brunkebergsgatan Stockholm
  - Discussions and networking
  - Courses

    Extensive course activity 1940-70
    Donald Campbell from Gordon Brown's Servomechanism Laboratory at MIT gave the first course in servo-systems in 1948 invited by Teknologföreningen 1948 (Invitation initiated by Bertil Palme Philips Teleindustries)
- Royal Swedish Academy of Engineering IVA
  - Scholarships

    Computers: IAS Princeton and Besk
    Control: Qvarnström (Bofors), Åslund (KTH), Sandblad (ASEA)
  - National committee for IFAC
  - Instrument tekniska föreningen ITF 1961

Nils Gustaf Dalén 1869-1937 and AGA

- Chalmers 1896
- One year with Stodola (Hurwitz stability criterion) at ETH
- CTO Svenska Karbid and Acetylen 1901
- CEO Svenska Aktiebolaget Gasackumulator (AGA) 1909
- Nobel Prize in Physics 1912
- AGA highly diversified company in gyroscopes, optics and military electronics
- AGA part Linde Group 2000
- Research grants from VR? Too low h-index
- Vinnova would have liked him!

  Scientific recognition, inventor
  entrepreneur, businessman
- Has he contributed to Chalmers Shanghai rating?

Nobel Prize in Physics 1912



Gustaf Dalén: for his invention of automatic regulators for use in conjunction with gas accumulators for illuminating lighthouses and buoys.

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Power Systems

- Turbine controller (Ytterberg ABB)
- Strong collaboration between ABB and Swedish State Power Board (Vattenfall)
- Problems with long distance power transmission
- Ivar Herlitz

  Engineer KTH, work at ABB
  Harvard and GE Schenectady
  Riverside Power Co
  Stanford
  PhD KTH. The Stability of Long Transmission Lines. KTH 1928
- Uno Lamm and HVDC
- The nuclear reactors AB Atomenergi
- Asea Atom
- Sydkraft (EON)

Herlitz Stability Analysis

The swing equation

$$\omega_0 J \frac{d^2\delta}{dt^2} = P_g - P_c \sin\delta, \qquad P_{max} = \frac{V_f V_l}{X}$$

δ angle deviation, V_g generator voltage, V_l line voltage, X line reactance, P_g generated power, P_c consumed power. Notice no damping. If

$$a = \frac{P_g}{P_c} > 1$$

there is an equilibrium $\delta = \delta_0 = \arcsin(1/a)$

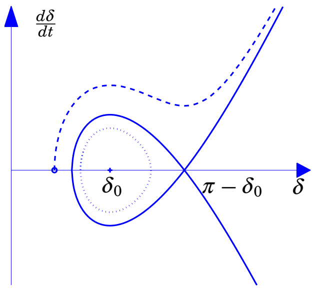
Energy equation

$$\omega_0 J \Big(\frac{1}{2}\frac{d\delta}{dt}\Big)^2 - P_g\delta + aP_{max}\cos\delta = C$$

Phase Plane - No Damping

$$\omega_0 J \frac{d^2\delta}{dt^2} = P_g - P_{max}\sin\delta, \quad \omega_0 J \Big(\frac{1}{2}\frac{d\delta}{dt}\Big)^2 - P_g\delta + aP_{max}\cos\delta = C,$$

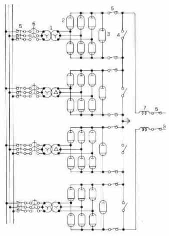
Center at δ_0
Node at $\pi - \delta_0$
Homo-clinic orbit through center



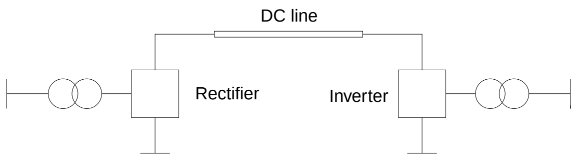
High Voltage DC Transmission

- Uno Lamm ABB

  CI KTH 1927, ABB, PhD KTH 1943
- Cable to Gotland 1954 - mercury arc switches
- An interesting hybrid system
- ASEA achieved global dominance
- Major improvements with thyristor valves
- Hardware and systems principles
- Safety a major concern



HVDC Control Principle



- Direction of power flow can change rapidly
- Find a sound principle to control power transmission (architecture)! The current is

$$I = \frac{V_t - V_r}{R}$$

. Can this relation be used safely?
- Find a good alternative

ASEA - Masters of Frequency Response

- The Central Laboratory
- Aage Garde and Erik Persson
- How control problems were solved
- Impact of Nyquist's stability critierion
- Brave experimentation with Frequency Response
- Interesting design methods
- Active on the international arena CIGRE, IFAC, IEE

  Aage Garde participated in the Cranfield konferensen, member of IFAC committee
  Participation at the ASME Frequency Response Symposium New York
  Erik Persson IFAC Basel 1963
- At the frontline in the mide 1950s
- Missed the paradigm shift in 1960, optimal control, computer control and Kalman filtering
- Unfortunate influence on the Chair of Control at KTH

When the Nyquist Theorem arrived at ASEA

- Nyquist Regeneration Theory Paper 1932
- Control activity at ASEA
  - Central laboratory Aage Garde/Erik Persson
  - Model-Solve Characteristic Equation-Guess-Modify
  - Computational tools - mechanical calculator
  - The Nyquist revolution
  - Garde, A (1948) Frekvensanalytisk behandling av reglersystem. Aseas tidning (Frequency Analysis of Control Systems) 27-33
  - Garde, A and Erik Persson (1960) Automatisk djupstyrning av ubåt. (Automatic Depth Control of Submarines) Aseas tidning 127-131.
- Naval Procurement Agency (Marinförvaltningen)
- Seminars by Garde and Persson in Lund

Depth Control of Submarines

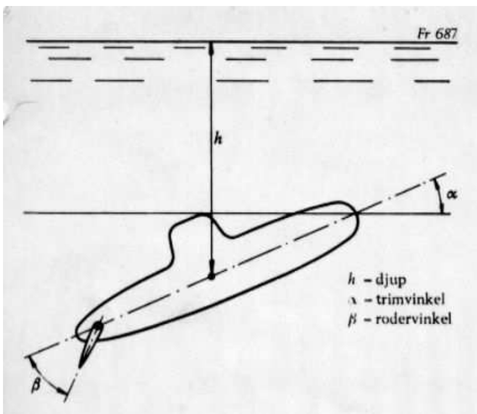
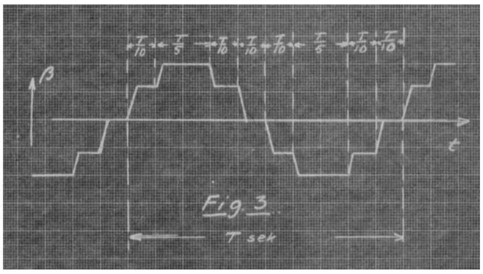


Fig. 1. Fartyget i undervattensläge.

Modeling Using Frequency Response

- How to generate sine-waves and how to measure and record depth and trim?



Results

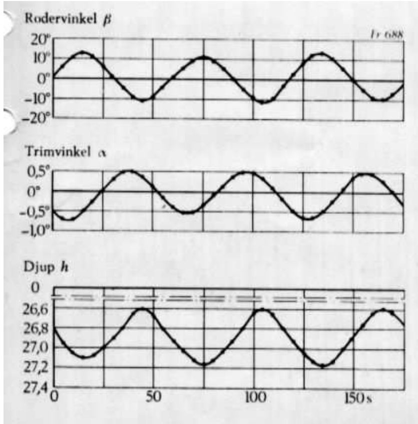
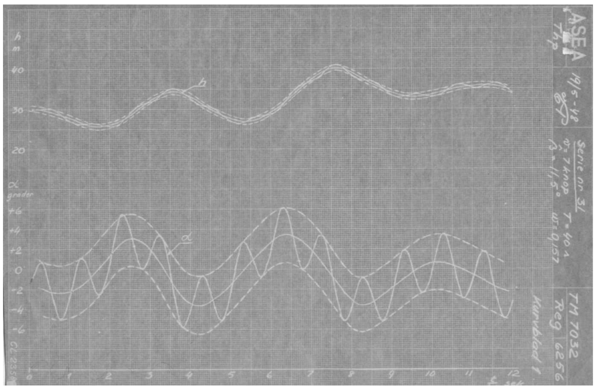
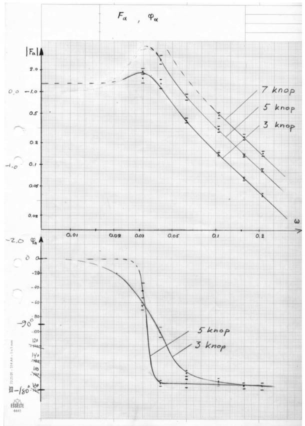


Fig. 2. Registreringar från frekvensanalysproven.

At High Speeds



Bode Plot Rudder to Trim



State Feedback using Nyquist Plots

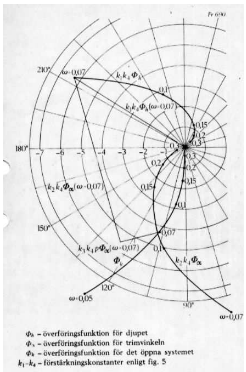


Fig. 4. Nyquist-diagram för regleringssystemet.

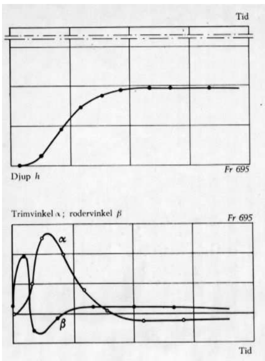


Fig. 9. Regleringsförlopp vid omställning av djupet.

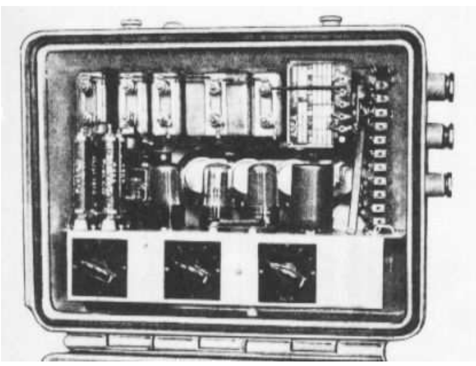
Implementation

- Sensors for depth and trim (damped pendulum)
- Hydraulic actuator
- Controller

$$u = -r + k_4\Big(k_1 h + k_2\alpha + k_3\frac{d\alpha}{dt}\Big)$$

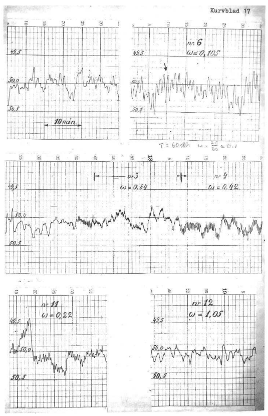
- Parameter k_4 changes with speed (gain scheduling)
- Implemented with vacuum tubes
- Persons Magic Black Box
- Because of the systems robustness and simple construction many systems have worked reliably for years

Electronics

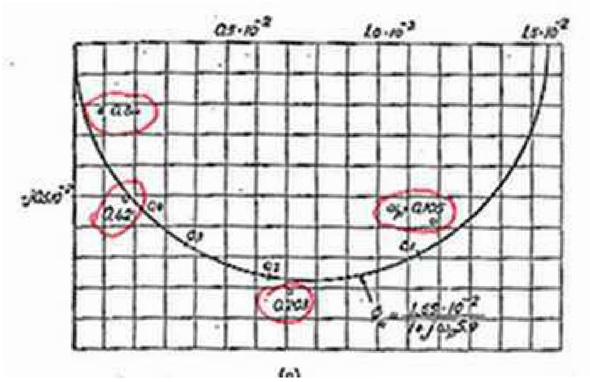


Dynamics of the Swedish Power Network

- Frequency response from power to frequency for Swedish power network
- Experiments Feb 25 - March 1 1949
- Oja, Persson, Almström
- Inject sinusoidal perturbations by changing a 50 MVA alternator
- Noisy signals correlations used to extract sinusoid
- Dynamics changes with time $P(s) = b/(s + a)$



Swedish Power Network 2



Summary

- Knowledge about the Nyquist theorem changed control at ASEA from trial and error to design
- Group of critical size at the Central Laboratory in Västerås
- A systematic way to obtain models from experimental data
- A nice design method, notice multi-variable aspects
- Fearless use of frequency response for modeling
- Many applications
- ASEA group active internationally CIGRE, ASME, IFAC

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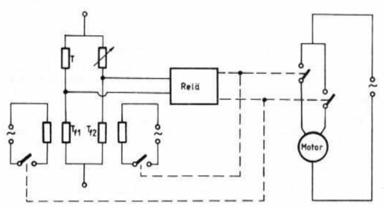
Process Control

- Billmanregulator 1932-1980
- Källeregulator 1933-1975
- Nordiska armaturfabriken NAF 1989-2004
- Pulp and paper industry
  - Research Groups at paper companies Billerud, Korsnäs, Modo, Stora, ...
- Central research institute STFI (Träforskningsinstitutet)
- ASEA
- The Axel Johnson Institut for industrial research, Karl Eklund Datema
- Elektronlund PBS 1973, Satt Control, Alfa Laval Automation, ABB
- Alfa Laval Automation
- ASEA-LME Automation
- IBM Nordic Laboratories

Billanregulator 1932-1980 - Stig Billman

- Civ. ing. KTH 1929, MS thesis "Behavior of temperature controllers"
- Birka regulator company automation of oil burners
- Forms Billmanregulator AB March 16, 1932 for constructing and selling oil burners
- Motor-driven valve with thermal feedback
- Pioneering work in temperature control of buildings
- Rapid expansion with strong board from large export companies AGA, Ericsson et al
- Global sales and manufacturing
- Incorporated in Landis & Gyr 1980
- Landis & Gyr acquired by Siemens Building Technology 1998

Billman's Electric Valve

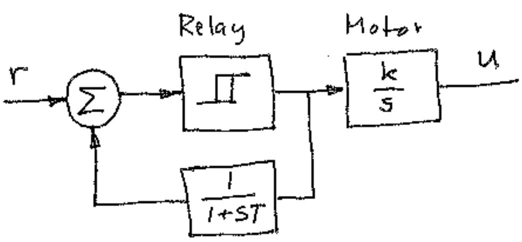


- Use motor with relay as an amplifier
- Thermistors give long time constants for integral control (thermal feedback)

Approximate relay by high gain use voltage balance

$$\frac{1}{1+sT}V = E, \qquad U = \frac{k_v}{s}V = \frac{k_v(1+sT)}{s}E$$

Block Diagram

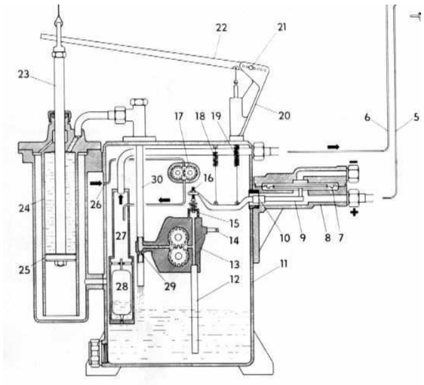


$$G(s) = \frac{k}{s}\frac{k_r}{1+\frac{k_r}{1+sT}} \approx k\frac{1+sT}{s} = kT + \frac{k}{s}$$

Källe regulator 1921-1969

- Torsten Källe 1893-1975
- Civ ing CTH 1919 worked at Billerud paper mill
- Started Källeregulator AB in Säffle 1921: Instrument and regulators for pulp and paper industry
- The Källe controller - an hydraulic actuator and a controller
- The carrot consistency sensor
- Bought by Bonniers (publisher with expansion vision) renamed EUR-Control
- Gustaf Dalén medal 1955 Chalmers engineering association
- IVA's Gold Medal for *his contribution to automatic control* 1955
- Donation for the professorship in automatic control at Chalmers 1963
- Ekman medal from Svenska Pappers- och Cellulosaingeniörsföreningen 1963

Källe's Controller

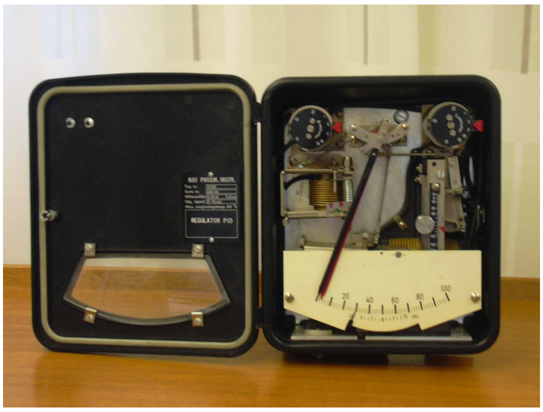


Clever hydraulic actuator integrated with a controller

Nordiska Armaturfabriken NAF

- Founded in Linköping 1899
- Valves, pressure sensors and regulators
- Manufactured valves in Lund
- Flight instruments, gyro horizons, altimeters
- Pneumatic controllers
- DCS system SDM20, SDM 30
- Relay auto-tuning based on KJs and Tore patent
- Development office in Lund Science Park Tore Hägglund worked there 1985-89
- Controller activity sold to Satt Control, Ahlsell, Alfa Laval Automation, ABB
- Valves sold to Flow Serve 2004

NAF's Pneumatic PID Controller



Tour & Andersson - TAC - Schneider

- 1875 A. H. Andersson & Co Christiania valves
- Tour Agenturer, Stockholm RVO valve cooperation with AHA
- 1952 First electronic controller TE1
- 1955 Motorized valve
- 1962 First transistorized controller TE5
- 1966 Incentive (Wallenberg) buys A. H. Andersson
- 1970 Incentive buys 75% of Tour Agenturer
- 1968-78 Computer Control of Buildings LTH
- 1975 Acquires part of Carl Olin AB DDC-6
- 1975 Computerized system 6000
- 1977 Tour & Andersson (TA) formed
- 1984 TA SYSTEM 7 energy control and building management
- 1995 TA Hydronics and TA Control
- 1996 Head office moves to Malmö
- 2003 Schneider Electric

IBM Nordic Laboratories 1960-1995

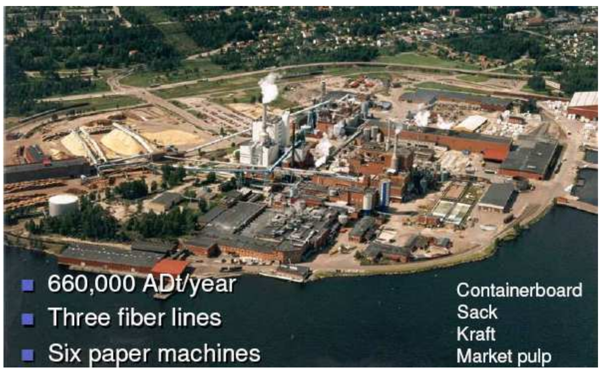
Euforia about computer control in the process industry

- Three tasks
  Develop technology for computer control
  Execute good demonstration projects
  Computer architecture for process control
- The Billerud project 1962-67
  Experimental determination of models for control of paper machine dynamics inspired the maximum likelihood method for system identification by Torsten Bohlin and KJÅ
  Minimum variance control KJÅ
  Excellent project, unfortunately no book
- IBM abandoned plans to buy an instrument company
- Impact on Academia
  K. J. Åström professor in control at LTH 1965
  Torsten Bohlin professor professor in control at KTH 1971
  Jorma Rissanen professor i control LiTH 1975
  Hans Andersin professor in computer science Helsingfors
  Dines Bjorner professor in computer science DTU 1976

The Billerud-IBM Project

- Background
  - IBM and Computer Control
  - Billerud Saab and Tryggve Bergek
- Goals
  - Billerud: Exploit computer control
  - IBM: Experience in computer control. Recover prestige!
  - What should a good process control computer look like?
  - Cram as much as possible into the system!
    On-line process control, production planning, production supervision, quality control, reporting
- Schedule
  - Start April 1963
  - Computer Installed December 1964
  - System identification and on-line control March 1965
  - Full operation September 1966
  - 40 man-years effort in about 3 years

The Billerud Plant



Basis Weight and Moisture Control

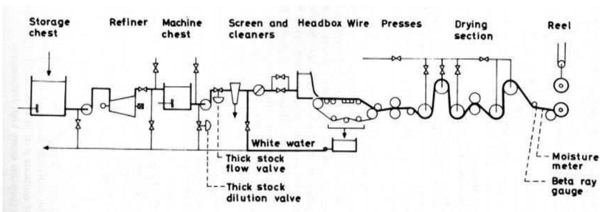
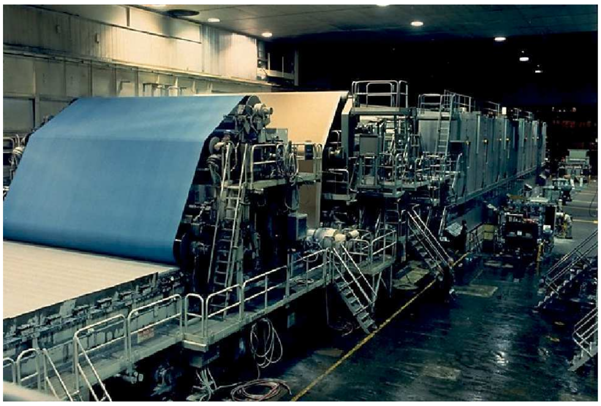


Fig. 6.9. Simplified diagram of a kraft paper machine.

- Two important loops
- Triangular coupling MISO works

The Drying Section



Computer Resources

- IBM 1720 (special version of 1620 decimal architecture)
- Core Memory 40k words (decimal digits variable word length)
- Disk 2 M decimal digits
- 80 Analog Inputs
- 22 Pulse Counts
- 100 Digital Inputs
- 45 Analog Outputs (Pulse width)
- 14 Digital Outputs
- Fastest sampling rate 3.6 s
- One hardware interrupt (special engineering)
- Home-brew real time operating system

Modeling and Control

- Good support from management Kai Kinberg:

  This is a showcase project! Don't hesitate to do something new and spectacular if you believe that you can pull it off and finish it on time.
- Process understanding, data logging and modifications (mixing tanks)
- Modeling by frequency response key for success of classical control
- Physical models may give dynamics but not disturbances
- Stochastic control theory is a natural formulation of industrial regulation problems
- Can we find something similar for state space systems?
- Big struggle to do real plant experiments
- Wasted a lot of time on historical data

Model Structures

Process model

$$dx = Axdt + Budt + dv$$
$$dy = Cxdt + de$$

Much redundancy $z = Tx$ + noise model. The innovation representation reduces redundancy of stochastics and filter gains appear explicitly in the model

$$dx = A\hat{x}dt + Budt + K(dy - C\hat{x}dt)$$
$$= (A - KC)\hat{x}dt + Budt + Kd\epsilon$$
$$dy = C\hat{x}dt + d\epsilon$$

Canonical form for MISO system removes remaining redundancy, discretization gives (C Kalman filter dynamics)

$$A(q)y(t) = B(q)u(t) + C(q)e(t)$$

Modeling from Data (Identification)

The Likelihood function (Bayes rule)

$$p(\mathcal{Y}_t, \theta) = p(y(t)|\mathcal{Y}_{t-1}, \theta) = \cdots = -\frac{1}{2}\sum_1^N \frac{\epsilon^2(t)}{\sigma^2} - \frac{N}{2}\log 2\pi\sigma^2$$

$$\theta = (a_1, \ldots, a_n, b_1, \ldots, b_n, c_1, \ldots, c_n, \epsilon(1), ..,)$$
$$Ay(t) = Bu(t) + Ce(t) \qquad C\epsilon(t) = Ay(t) - Bu(t)$$
$$\epsilon = \text{one step ahead prediction error}$$

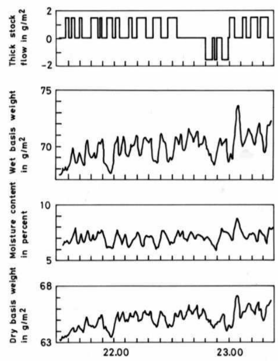
Efficient computations

$$\frac{\partial J}{\partial a_k} = \sum_1^N \epsilon(t)\frac{\partial \epsilon(t)}{\partial a_k}, \qquad C\frac{\partial \epsilon(t)}{\partial a_k} = q_k y(t)$$

- Estimate has nice properties Åström and Bohlin 1965
- The notion of identifiability
- Good match identification and control. Prediction error is minimized in both cases!

Practical Issues

- Sampling period
- To perturb or not to perturb
- Open or closed loop experiments
- Normal or perturbed operation
- Model validation
- 20 min for two-pass compilation of Fortran program!
- Skills and experiences



Minimum Variance (Moving Average Control)

Process model

$$Ay(t) = Bu(t) + Ce(t)$$

Factor $B = B^+B^-$, solve (minimum degree solution)

$$AF + B^-G = C$$

$$Cy = CFe + B^-(Ru + Sy), \qquad S = G \qquad R = FB^+$$

Control law and controlled output are

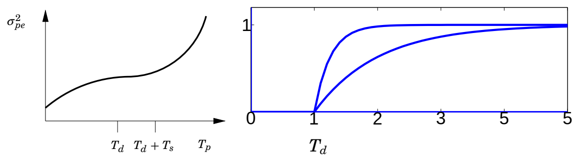
$$Ru(t) = -Sy(t), \qquad y(t) = Fe(t)$$

where $\deg F \geq$ pole excess of B/A

Sampling period is design variable!

True minimum variance control $V = E\frac{1}{T}\int_0^T y^2(t)dt$

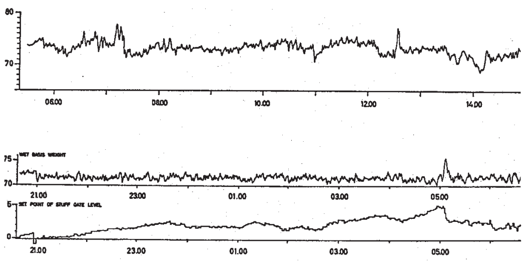
Performance and Robustness



- Strong similarity between all controller for systems with time delays, minimum variance, moving average and Smith predictor.

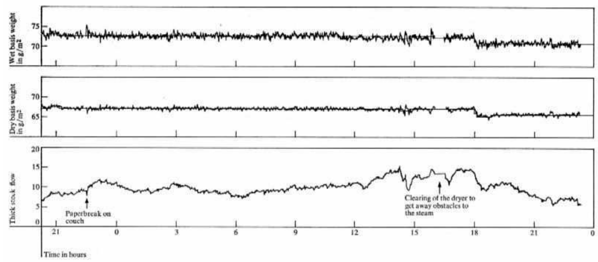
  It is dangerous to be greedy!
- Rule of thumb: no more than 1-4 samples per dead time motivated by simulation.
- Prediction horizon T_p is the tuning variable

Results

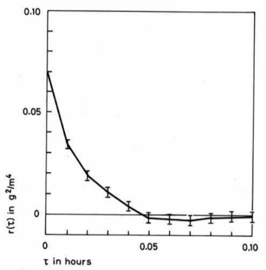


Controller removes the low frequency component

Results



Summary of Minimum Variance Control



- Regulation can be done effectively by minimum variance control
- Easy to validate

  $r(t) = 0, \quad t \geq k$
- Prediction horizon is the **design variable**!
- Robustness depends critically on the sampling period
- The Harris Index
- OK to assess but why not adapt?

Publications

Åström, K. J. and T. Bohlin, Numerical Identification of Linear Dynamic Systems from Normal Operating Records. In P. H. Hammond (editor), *Theory of Self-Adaptive Control Systems.* Plenum Press New York 1966, Proc IFAC Symposium on Self-Adaptive Control, Teddington 1964.

Åström, K. J. Computer Control of a Paper Machine - an Application of Linear Stochastic Control Theory. IBM J. of Research and Development 11 (1967) 389-405.

Ekstrœm, Å (editor) Integrated Computer Control of a Paper Machine. Proc. Billerund-IBM Symposium, Billerud June 1966.

Summary

- Extremely good and farsighted management

  Kai Kinberg IBM Nordic Laboratory, Tryggve Bergek Billerud
- Good resources with competent and interested participants
- Good mix of people with many short term participants
- Open atmosphere with pressure on dead-lines and results
- A successful flagship installation
- Straw-man for computer architecture for process control

  IBM 1800, IBM 360
- Method for identification of stochastic models

  Basic theory: consistency, efficiency, persistent excitation
  Engineering practice: input design, execution of experiments
- Minimum variance control
- Project well documented in IBM reports and a few papers
  but we should have written a book (Bellman's advice)
- Personally a great learning experience - BUT

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The Defense Industry - The Large Projects

- *Alliansfri i fred och neutral i krig - Non-aligned in peace neutral in war*
- Stril 60, JA37 Viggen, (Gripen)
- FOA 1945

  Chemistry, Physics Electronics, Operations research
  Bäckebobomben (Boestad, Luthander)
  TTN Gruppen Bengt Joel Andersson
- Aeronautics KTH Prof Luthander
- The Army, Navy and Air force Procurement Agencies (Arme-, flyg- och marinförvaltningarna)

  Avionics Bureau
  Missile Bureau
- Saab
- Bofors - Gun-sights
- Volvo Flygmotor
- The Electronics Industry

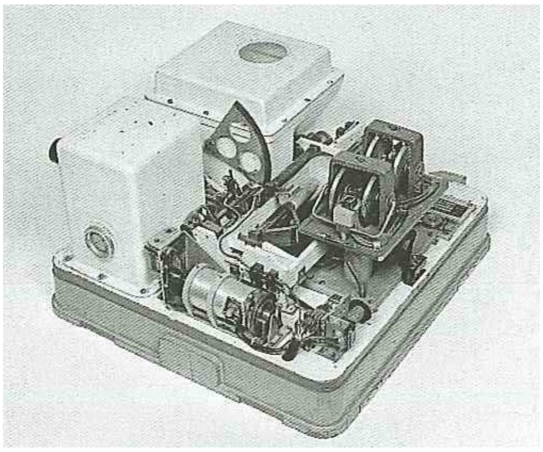
  AGA, Arenco, Ericsson, Philips, TUAB

Gun Sights

- Draper and Sperry
- Wilkinson Saab
- Gun-sight for dive bombing

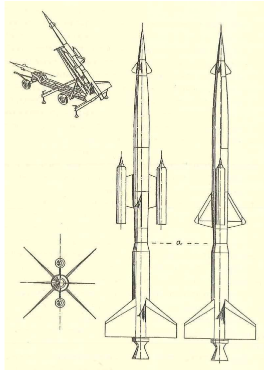
  Air-driven gyroscope, electro-mechanical analog computer, nonlinear function generator in the form of an asymmetrical rotating body. Gyro manufactured by NAF, function generator by Arenco (Tändsticksbolaget)
- Made in large numbers in the US by licensing
- Wilkinson E. Dive Bombing. PhD thesis, Royal Institute of Technology, Stockholm, Sweden, June 20, 1947

Wilkinson's Gun Sight



Missile Guidance

- The threat
- Viggen
- KTH Flygteknik Prof Sten Luthander
- Bäckebobomben 19440613
- Gustav Boestad KTH
- Saab R-System
- The TTN Group



FOA

Missile guidance

- Thorvald Persson
  Lars Erik Zachrisson
  proportional navigation
- Inertial navigation
  Philips, AGA, Saab
  MIT Draper

Analog computing

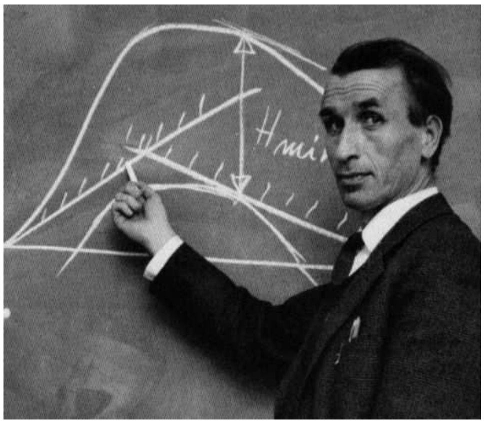
- Jonas Agerberg
  SAMS
  ADA

Radar, computers, Besk

Brodin, Persson och Jahnberg

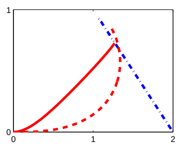
RB 04 early air-to-sea missile

Lars Erik Zachrisson



Lars Erik Zachrisson 1919-1980

- Engineering Physics KTH 1945
- FOA 1947-57 missile guidance
- Proportional navigation 1946.
  Control principle for guidance
  Patent and analysis



- Markov Games 1955 (Isaac's 1965)
  A tank duel with game theoretic implications, 1955, 1957
  Markov games. In advances of Game Theory. Princeton University Press 1964. Isaacs bok 1965.
- Saab R-system 1957-63
- Docent in Automatic Control KTH 1959
- Optimization and System Theory KTH
- Professor System Theory and Optimization KTH 1963
- Anders Lindquist 1972 (Z:s first PhD student)

TTN Gruppen

- Goal: Understand inertial navigation and guidance
- Structure
  FFV: Torsten Bergens
  FOA: Thorvald Persson
  KTH: Bengt Joel Anderson, Jahnberg, Åslund, KJÅ
  Aga, Philips, Saab,
  The MIT connection

- Free-wheeling, chaotic
  FOA's kulgyro, ...
- Free access to Besk (The only Swedish Computer)
- The MIT connection
- Fantastic learning experience BUT many constraints

Vertical, Vertical, Who's got the Vertical?

- Strong scepticism from George Gamov and others
- Drapers coup: Classified Conference
  Gamov invited, did not come

Longitudinal position error with constant gyro drift

$$\ddot{e}_x = g\psi, \qquad \psi = \omega_0 t, \qquad e = \frac{g\omega_0}{6} t^3$$

Azimuth error

$$\dot{e}_a = U_0 \omega_0 t, \qquad e_a = \frac{U_0 \omega_0}{2} t^2$$

Assume $\omega_0 = 1°/s = 4.85 \times 10^{-6}$ [rad/s] $u_0 = 300$ m/s $t = 3600$ gives $e_x = 370$ km and $e_a = 9$ km.

Drift rates must be brought down to 0.01°/h. Azimuth gyro drift less important.

The Idea

Make a pendulum and increase its apparent moment of inertia with acceleration feedback

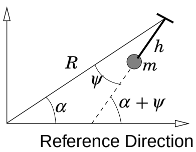
- Avoid closing the Schuler loop through the gimbals
- A single axis gyro can measure angular acceleration

Equations of motion:

$$J\frac{d^2\theta}{dt^2} = -mgh\psi + mRh\frac{d^2\alpha}{dt^2} + u$$

$$u = -k\frac{d^2\theta}{dt^2}$$

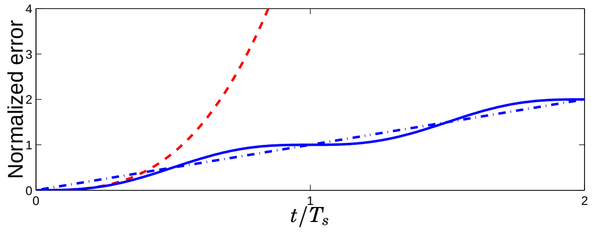
$$(J+k)\frac{d^2\theta}{dt^2} = -mgh\psi + mRh\frac{d^2\alpha}{dt^2} + u$$



Hence

$$(J+k)\frac{d^2\psi}{dt^2} + mgh\psi = (mRh - J - k)\frac{d^2\alpha}{dt^2}.$$

Schuler Tuning - Error Growth



$$e(t) = \frac{g\omega_0}{6}t^3, \qquad e(t) = R\omega_0\Big(t - \frac{1}{\omega_s}\sin(\omega_s t)\Big), \qquad \omega_s = \sqrt{g/R}$$

From Idea to Reality

- Analysis
- Experimental proof of concept - pure mechanical
- Electronic version
  - Great scepticism form seasoned Philip's servo expert - You will never be able to make it work - too high gain!!!
  - Working prototype made me a true believer of feedback
- Patent with Folke Hector Philips
- Trip to Nat Lab in Einhoven
- Scrutiny by Prof Casimir
  - Two-fluid model of super conductors
  - Casimir effect
- Funding and access to company plane
- Prototypes and test

Interesting Problems – BUT

- Modeling
  - Full 3D platform dynamics with reaction forces
  - Gyro drift

    Stochastics from physics - Brownian motion
    Nice agreements with experiments
- Control design - multivarible
- Sensor fusion
  - Combination with other sensors, radio, star trackers, Doppler (GPS)
  - Kalman filtering (kj IBM Federal Systems Division 1963)
- Initialization
  - Vertical alignment - Stochastic control
  - Gyrocompassing
- Very interesting technology – BUT Abomb and Secrets

Saab R-System

- Airplanes changed from carriers of black boxes to a system
- Formed 1954, inspired by Rand Corporation 1945
- Hans Olov Palme - aeronautical engineer KTH

  Enthusiastic, charismatic, visionary leader
- Recruited a fantastic talent pool 75 persons in 1955

  Strong creativity, broad range and deep knowledge
  Tore Gullstrand, Bengt Gunnar Magnusson, Gösta Hellgren, Gösta Lindberg, Lars Erik Zachrisson, Viggo Wentzel
- Three groups: Systems, avionics, special projects
- Airborne computers, missile guidance, inertial navigation, simulation, operations analysis, Datasaab
- Electronics industry formed TUAB to compete

Automatic Control in Sweden

1. Introduction
2. Power Systems and ASEA
3. Process Control
4. Defense Projects
5. Academia
6. Summary

Theme: Followed the international pattern.

KTH

- First lectures 1949/50

  Laszlo von Hamos adjunct teacher from the Air-force
  Missile Bureau (robotvapenbyrån FMV) Gunnar Attebo
  Källeregulator and Bengt Sjöberg FMV as assistants
- von Hamos signed IFAC deklaration for Sweden in Heidelberg Sept 1956.
- Laszlo von Hamos appointed professor 1959
- FOA sponsored Dept of System theory and Optimization for Lars Erik Zachrisson 1964-69. Regular Chair 1969.
- Torsten Bohlin 1971
- Bo Wahlberg 1991

CTH

- Stig Ekelöf professor in electrical engineering - the differential analyzer
- Henry Wallman gave course for electrical engineers 1953-55

  Wallman came from the Radiation Laboratory MIT
- Robert Magnusson Control for Telecommunication 1959

  Charlie Davidson, ...
- Professorship partially financed by Torsten Källe 1962 Birger Qvarnström appointed 1963

  Qvarnström: KTH Aeronatutics analog computing, Bofors
  Åke Blomqvist, hydraulic servos for gun pointing, Dial 1958,
  IVA scholarship , Träforskningsinstitutet STFI
- Separate courses in control and control for communication engineers continued for a long time
- Bo Egardt 1989

LTH, LiTH, Uppsala, Luleå

- Lund

  KJÅ1965, BW 1989
- Linköping

  Jorma Rissanen 1975 Lennart Ljung 1976
  Torkel Glad 1988, Lars Nielsen 1992
- Uppsala

  Torsten Söderström, Associate Prof 1974, Professor 1982
- Luleå

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Summary

- Followed the international pattern with delay
- Early activity in industry and research institutes
- Sending engineers abroad (ASEA, IVA) very useful
- Large military projects and industrial labs critical
  FOA, Saab, Asea, Bofors, Philips, IBM Nordic Lab
- Analog computing a glue between groups SAMS (Jonas Agerberg) – a precursor to Reglermötet
- University activity late in an international but a dramatic expansion in the 1990s
- Collaboration with ITF (ISA) was a missed opportunity, compare Norway and Finland.
  - Finnish Society of Automation 1953
  - Norwegian Society in Automatic Control NFA 1958