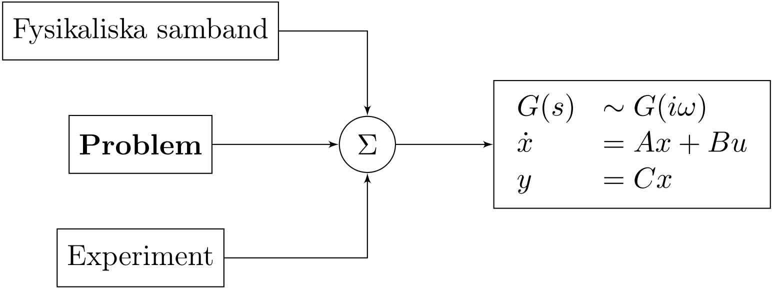
Föreläsning 12 (Sista)
Reglerteknik AK

©Bo Wahlberg

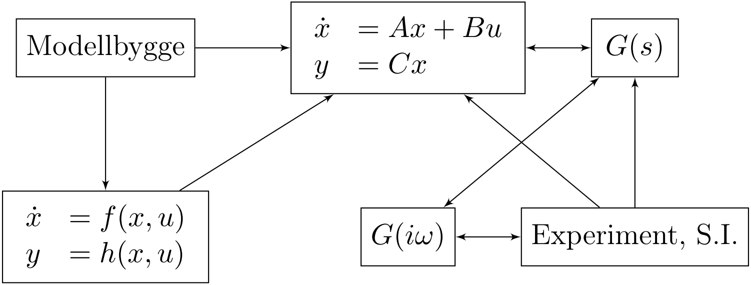
Avdelningen för reglerteknik
Skolan för elektro- och systemteknik

7 Oktober 2015

Sammanfattning



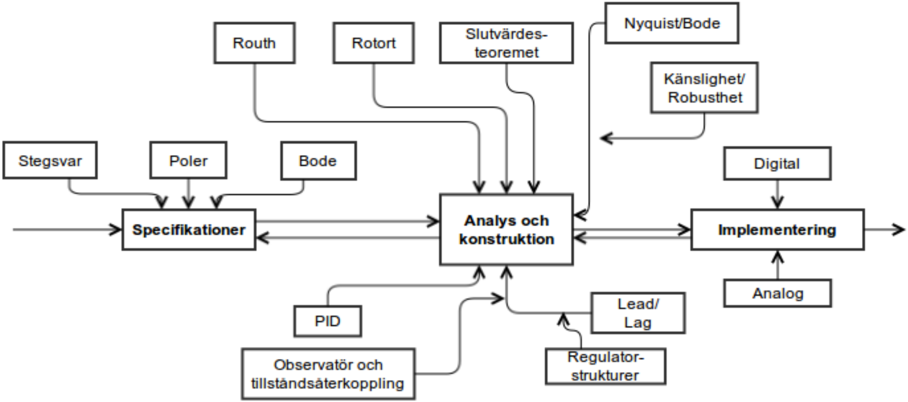
Sammanfattning



Verkliga system är komplicerade:

$$G^0(s) = G(s)\big[1 + \Delta_G(s)\big], \quad |\Delta_G(i\omega)| \leq g(\omega) \;\; \forall \;\; \omega$$

Sammanfattning



Sammanfattning - Rotort

Rotort:

I. n Startpunkter $(K = 0)$

II. m Ändpunkter $(K = \infty)$

III. Var ligger ∞? (Asymptoter)
Riktning: $\frac{\pi}{n-m} + k \cdot \frac{2\pi}{n-m}$
Skärningspunkt: $\frac{1}{n-m}\left(\sum p_i - \sum q_j\right)$

IV. Skärning med reella axeln. "*Udda summa*"

V. Skärning med imaginära axeln. Ansätt $s = i\omega$

VI. Rita rotort och **dra slutsats**

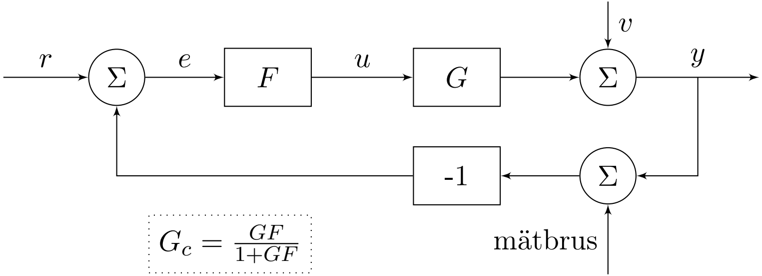
Sammanfattning - Slutvärdesteoremet

Slutvärdesteoremet:

Kom ihåg att kolla att slutvärdet existerar! (slutna systemets poler strikt i V.H.P.)

Steg $\frac{1}{s}$

Ramp $\frac{1}{s^2}$



$G_c = \frac{GF}{1+GF}$

Tidsdomänen:

Stigtid: T_r

Insvängningstid: T_s

Översläng: M

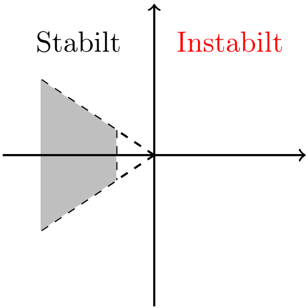
Frekvensdomänen:

Bandbredd: ω_B

Resonanstopp: M_p

Resonansfrekvens: ω_r

Sammanfattning - Poler



Avstånd till origo ≈ snabbhet
Vinkel ≈ svängighet

Sammanfattning - Poler

Nyquist:
$G_o(i\omega)$

Bode:
$|G_o(i\omega)|,\ \arg\left[G_o(i\omega)\right]$

Tolkning $\leftrightarrow$ rita

$$\left.\begin{array}{ll} \text{skärfrekvens:} & \omega_c \\ \text{fasmarginal:} & \varphi_m \end{array}\right\} \leftrightsquigarrow \quad |G(i\omega_c)| = 1$$

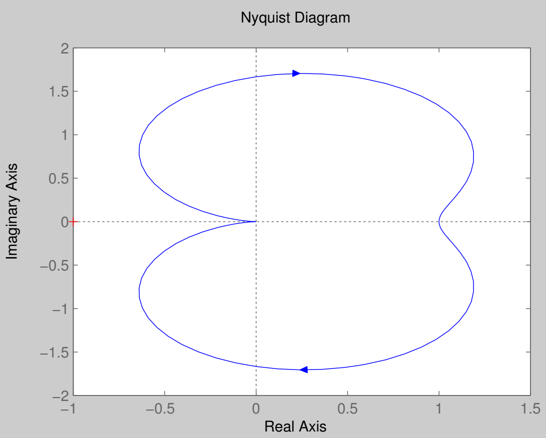
Amplitudmarginalen kan läsas av i Bodediagram eller Nyquistkurva (se figur 5.2 samt 5.3 i boken).

Sammanfattning - Nyquistkriteriet

Antag att $G_o(s)$ saknar poler i H.H.P. och att Nyquistkurvan **ej** omcirklar -1.

$\Rightarrow$ $G_c(s)$ saknar poler i H.H.P.

$\Rightarrow$ Stabilt återkopplat system.



Sammanfattning - Bodediagram

Öppna systemets Bodediagram $\leftrightarrow$ Slutna systemets Bodediagram

Fördubbla ω_c $\leftrightsquigarrow$ Fördubbla ω_B

$\varphi_m \sim M_p$

liten $\rightarrow$ *stor* $(\varphi_m \approx 50^\circ - 60^\circ \text{ OK})$

$G_o(i\omega)$ stor $\Rightarrow G_c(i\omega) \approx 1$

$G_o(i\omega) \approx -1 \Rightarrow G_c(i\omega)$ stor

Sammanfattning - Känslighet och störningar

Känslighet (störningar):

$$S = \frac{1}{1 + FG}$$

Robusthet (modellfel):

$$T = \frac{FG}{1 + FG} = 1 - S$$

Sammanfattning - Konstruktion

PID-regulator:

$$U(s) = K\left(1 + \frac{1}{T_I}\frac{1}{s} + T_D s\right) = K_P + K_I\frac{1}{s} + K_D s$$

Lead-/Lag-länk:

$$F(s) = K\frac{\tau_D s + 1}{\beta\tau_D s + 1}\frac{\tau_I s + 1}{\tau_I s + \gamma}$$

Önska $\bar{\omega}_c$ (Lägg till 5.7° extra på fasmarginalen, φ_m)
$\implies \beta \implies \tau_D \implies K$

$\tau_I = \frac{10}{\bar{\omega}_c}$ (iterera)

Välj γ liten.

Sammanfattning - Tillståndsteori

$$\begin{cases} \dot{x} &= Ax + Bu \\ y &= Cx \end{cases}$$

$$\boxed{\begin{gathered} \dot{\hat{x}} = A\hat{x} + Bu + K(y - C\hat{x}) \\ \det\left[sI - (A - KC)\right] = 0 \end{gathered}}$$

$$\boxed{\begin{gathered} u = -Lx + l_0 r \\ \det\left[sI - (A - BL)\right] = 0 \end{gathered}}$$

$$\Downarrow$$

$$\boxed{u = -L\hat{x} + l_0 r}$$

Styrbarhet + Observerbarhet

Sammanfattning

Regulatorstrukturer:

- Framkoppling
- Kaskadreglering
- Otto Smith

Implementering:

- Euler bakåt
- Tustins formuel

Differentialekvationer $\mapsto$ differensekvationer

Tentan 30 oktober

- Man får ha boken och Beta med sig (samt. miniräknare).
  Läs boken innan tentan!

- Problemlösning (ej utantillavskrivningar). Träna på gamla tentor!

- **Observera** att man måste vara anmäld för att få skriva tentan!

Frågestund i V35, onsdagen den 28 oktober, 2015 kl 15:15-17:00

Mer kurser

Master's programme in Systems, Control and Robotics!

- Olinjär reglering, Elling Jacobsen, period 2
- Hybrida och inbyggda reglersystem, Dimos Dimarogonas, period 3
- Reglerteknik, fortsättningskurs, Elling Jacobsen, period 4
- Modellering av dynamiska system, Cristain Rojas, period 1,
- Automatic Control Project Course, Jonas Mårtensson, period 1-2

Nya kurser

Master's programme in Systems, Control and Robotics!

- Model Predictive Control, Mikael Johansson, period 1
- Stochastic Control and Optimization, Alexandre Proutiere, period 2

Mastermässa Torsdag 15 oktober kl 16-18.

Your Future

Disruptive technologies: Advances that will transform life, business, and the global economy

According to McKinsey Global Institute (Maj 2103):

Also check Wallenberg Autonomous Systems Program (WASP)

Speed, scope, and economic value at stake of 12 potentially economically disruptive technologies

	Illustrative rates of technology improvement and diffusion	Illustrative groups, products, and resources that could be impacted[1]	Illustrative pools of economic value that could be impacted[1]
Mobile Internet	**$5 million vs. $400[2]** Price of the fastest supercomputer in 1975 vs. that of an iPhone 4 today, equal in performance (MFLOPS) **6x** Growth in sales of smartphones and tablets since launch of iPhone in 2007	**4.3 billion** People remaining to be connected to the Internet, potentially through mobile Internet **1 billion** Transaction and interaction workers, nearly 40% of global workforce	**$1.7 trillion** GDP related to the Internet **$25 trillion** Interaction and transaction worker employment costs, 70% of global employment costs
Automation of knowledge work	**100x** Increase in computing power from IBM's Deep Blue (chess champion in 1997) to Watson (Jeopardy winner in 2011) **400+ million** Increase in number of users of intelligent digital assistants like Siri and Google Now in past 5 years	**230+ million** Knowledge workers, 9% of global workforce **1.1 billion** Smartphone users, with potential to use automated digital assistance apps	**$9+ trillion** Knowledge worker employment costs, 27% of global employment costs
The Internet of Things	**300%** Increase in connected machine-to-machine devices over past 5 years **80–90%** Price decline in MEMS (microelectromechanical systems) sensors in past 5 years	**1 trillion** Things that could be connected to the Internet across industries such as manufacturing, health care, and mining **100 million** Global machine to machine (M2M) device connections across sectors like transportation, security, health care, and utilities	**$36 trillion** Operating costs of key affected industries (manufacturing, health care, and mining)
Cloud technology	**18 months** Time to double server performance per dollar **3x** Monthly cost of owning a server vs. renting in the cloud	**2 billion** Global users of cloud-based email services like Gmail, Yahoo, and Hotmail **80%** North American institutions hosting or planning to host critical applications on the cloud	**$1.7 trillion** GDP related to the Internet **$3 trillion** Enterprise IT spend
Advanced robotics	**75–85%** Lower price for Baxter[3] than a typical industrial robot **170%** Growth in sales of industrial robots, 2009–11	**320 million** Manufacturing workers, 12% of global workforce **250 million** Annual major surgeries	**$6 trillion** Manufacturing worker employment costs, 19% of global employment costs **$2–3 trillion** Cost of major surgeries
Autonomous and near-autonomous vehicles	**7** Miles driven by top-performing driverless car in 2004 DARPA Grand Challenge along a 150-mile route **1,540** Miles cumulatively driven by cars competing in 2005 Grand Challenge **300,000+** Miles driven by Google's autonomous cars with only 1 accident (which was human-caused)	**1 billion** Cars and trucks globally **450,000** Civilian, military, and general aviation aircraft in the world	**$4 trillion** Automobile industry revenue **$155 billion** Revenue from sales of civilian, military, and general aviation aircraft

Next-generation genomics	**10 months** Time to double sequencing speed per dollar **100x** Increase in acreage of genetically modified crops, 1996–2012	**26 million** Annual deaths from cancer, cardiovascular disease, or type 2 diabetes **2.5 billion** People employed in agriculture	**$6.5 trillion** Global health-care costs **$1.1 trillion** Global value of wheat, rice, maize, soy, and barley
Energy storage	**40%** Price decline for a lithium-ion battery pack in an electric vehicle since 2009	**1 billion** Cars and trucks globally **1.2 billion** People without access to electricity	**$2.5 trillion** Revenue from global consumption of gasoline and diesel **$100 billion** Estimated value of electricity for households currently without access
3D printing	**90%** Lower price for a home 3D printer vs. 4 years ago **4x** Increase in additive manufacturing revenue in past 10 years	**320 million** Manufacturing workers, 12% of global workforce **8 billion** Annual number of toys manufactured globally	**$11 trillion** Global manufacturing GDP **$85 billion** Revenue from global toy sales
Advanced materials	**$1,000 vs. $50** Difference in price of 1 gram of nanotubes over 10 years **115x** Strength-to-weight ratio of carbon nanotubes vs. steel	**7.6 million tons** Annual global silicon consumption **45,000 metric tons** Annual global carbon fiber consumption	**$1.2 trillion** Revenue from global semiconductor sales **$4 billion** Revenue from global carbon fiber sales
Advanced oil and gas exploration and recovery	**3x** Increase in efficiency of US gas wells, 2007–11 **2x** Increase in efficiency of US oil wells, 2007–11	**22 billion** Barrels of oil equivalent in natural gas produced globally **30 billion** Barrels of crude oil produced globally	**$800 billion** Revenue from global sales of natural gas **$3.4 trillion** Revenue from global sales of crude oil
Renewable energy	**85%** Lower price for a solar photovoltaic cell per watt since 2000 **19x** Growth in solar photovoltaic and wind generation capacity since 2000	**21,000 TWh** Annual global electricity consumption **13 billion tons** Annual CO_2 emissions from electricity generation, more than from all cars, trucks, and planes	**$3.5 trillion** Value of global electricity consumption **$80 billion** Value of global carbon market transactions

1 Not comprehensive; indicative groups, products, and resources only.
2 For CDC-7600, considered the world's fastest computer from 1969 to 1975; equivalent to $32 million in 2013 at an average inflation rate of 4.3% per year since launch in 1969.
3 Baxter is a general-purpose basic manufacturing robot developed by startup Rethink Robotics.
SOURCE: McKinsey Global Institute analysis