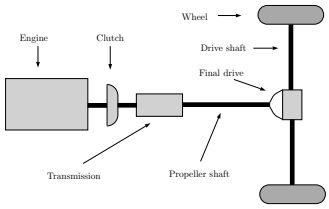
Drivlina - Reglering

Reglera rotationshastigheter och moment



Drivlina - Reglering

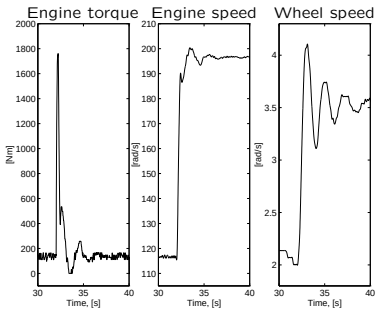
Viktiga tillämpningar

- driveline speed control (farthållning)
- driveline control for gear shifting
  ("automatväxling" med motorstyrning)

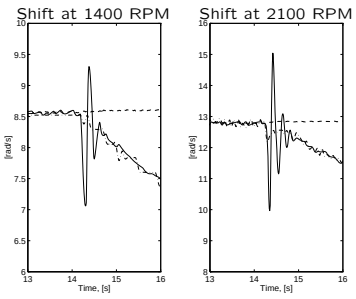
Drivlina Reglering

Varför är det inte enkelt?

Mätningar illustrerar svårigheter



Stegsvar t=32 s:
motorvarvtal–dämpat, hjulvarvtal–svängigt



Från växelläge till neutralläge

Drivlina - Modellering

Modell

$$\begin{aligned}(J_m + J_t/i_t^2 + J_f/i_t^2 i_f^2)\ddot{\theta}_m &= M_m - M_{fr:m} - (b_t/i_t^2 + b_f/i_t^2 i_f^2)\dot{\theta}_m \\ &\quad -k(\theta_m/i_t i_f - \theta_w)/i_t i_f \\ &\quad -c(\dot{\theta}_m/i_t i_f - \dot{\theta}_w)/i_t i_f \\ (J_w + m r_w^2)\ddot{\theta}_w &= k(\theta_m/i_t i_f - \theta_w) + c(\dot{\theta}_m/i_t i_f - \dot{\theta}_w) \\ &\quad -(b_w + m c_{r2} r_w^2)\dot{\theta}_w - \frac{1}{2} c_w A_a \rho_a r_w^3 \dot{\theta}_w^2 \\ &\quad -r_w m\,(c_{r1} + g sin(\alpha))\end{aligned}$$

Tillstånd

$$x_1 = \theta_m/i_t i_f - \theta_w, \quad x_2 = \dot{\theta}_m, \quad x_3 = \dot{\theta}_w$$

Drivlina - Reglering

Mätsignal

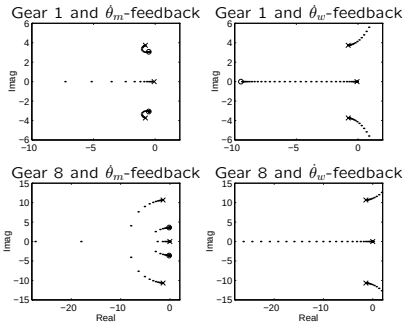
$$y = Cx + e$$

Olika sensorer

$$\begin{aligned}C_m &= (0\ 1\ 0) \\ C_w &= (0\ 0\ 1)\end{aligned}$$

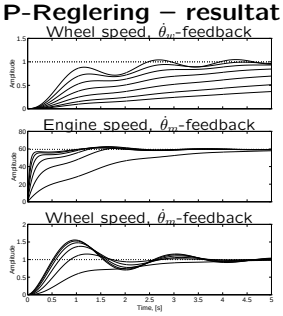
Prestanda variabel z

$$z = Mx + Du$$



Rotort, P-reglering från motorvarvtal och hjulvarvtal:
över – växel 1, under – växel 8. Kryss öppna systemets poler.
P-reglering av hjulvarvtalet kan ge instabilt system.

P-Reglering – resultat

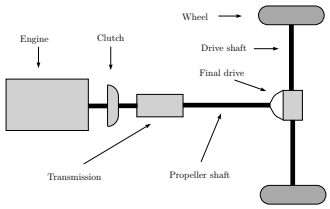


Stegsvar för system reglerade med P-regulator olika återkopplings signaler.

Drivlina - Reglering

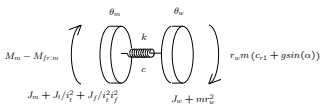
Reglera rotationshastigheter och moment

Tillämpningar:
-hastighetsreglering
-växlingsreglering

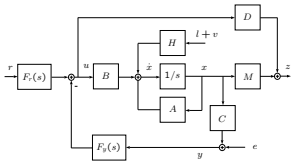


Drivlina - Reglering

Använd torsionsmodellen



Drivlina - Reglering



Regulatorer

F_y återkoppling "placering av poler"

F_r framkoppling "servoegenskaper"

Drivlina - Reglering

Hur var det nu man gjorde mer anvancerad reglering än P-reglering?

Med

$u = M_m - M_{fr:m}$

tillståndsrepresentation

$$\dot{x} = Ax + Bu + H\ l \tag{1}$$

Drivlina - Reglering

$$\begin{aligned} x_1 &= \theta_m/i_t i_f - \theta_w \\ x_2 &= \dot{\theta}_m \\ x_3 &= \dot{\theta}_w \\ l &= r_w m\,(c_{r1} + g sin(\alpha)) \end{aligned} \tag{2}$$

$$A = \begin{pmatrix} 0 & 1/i & -1 \\ -k/iJ_1 & -(b_1 + c/i^2)/J_1 & c/iJ_1 \\ k/J_2 & c/iJ_2 & -(c+b_2)/J_2 \end{pmatrix},$$

$$B = \begin{pmatrix} 0 \\ 1/J_1 \\ 0 \end{pmatrix}, \quad H = \begin{pmatrix} 0 \\ 0 \\ -1/J_2 \end{pmatrix} \tag{3}$$

$$\begin{aligned} i &= i_t i_f \\ J_1 &= J_m + J_t/i_t^2 + J_f/i_t^2 i_f^2 \\ J_2 &= J_w + m r_w^2 \\ b_1 &= b_t/i_t^2 + b_f/i_t^2 i_f^2 \\ b_2 &= b_w + m c_{r2} r_w^2 \end{aligned} \tag{4}$$

Drivlina - Reglering

Tillståndåterkoppling

$$u = l_0 r - K_c \hat{x} \tag{5}$$

K_c är tillståndåterkopplingsmatrisen

Kalman-filter

$$\dot{\hat{x}} = A\hat{x} + Bu + K_f(y - C\hat{x}) \tag{6}$$

K_f är Kalmanförstärkningsmatrisen.

Drivlina - Reglering

Repetition av Reglerteknik

Man kan placera polerna

Placera polerna så att dynamiken blir väl dämpad

Regulatorn sköter då detta

Aktiv dämpning

Drivlina - Reglering

Fungerar Aktiv dämpning?

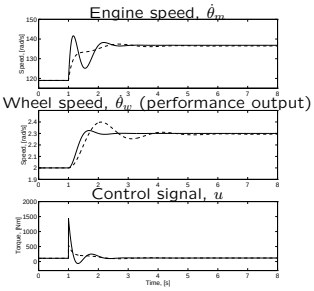
I så fall: Hur?

Jämför med klassisk RQV

$$u = u_0 + K_p(ri - \dot{\theta}_m) \tag{7}$$

Drivlina - Reglering

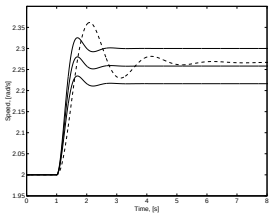
Ja, det fungerar



Jämförelse vid ungefär samma snabbhet.

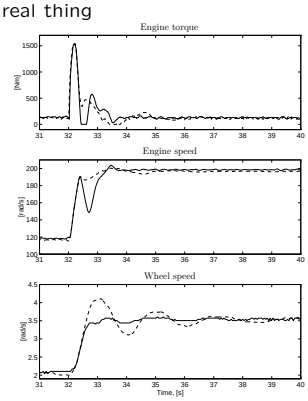
Drivlina - Reglering

Man kan trimma stationära felet



Stationära felet skiljt från noll kan vara intressant för körkänslans skull.

Fältförsök – The real thing



Aktiv dämpning (heldragen) – Traditional RQV (streckad).

Drivlina - Modellering

Ytterligare motoregenskaper som är viktiga i ett verkligt fall.

Maximum torque delimiter

Diesel smoke delimiter If the turbo pressure is low and a high engine torque is demanded, diesel smoke emissions will increase to an unacceptable level.

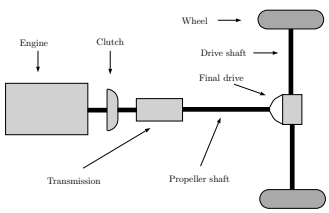
Transfer function from fuel to engine

Engine friction The engine output torque transferred to the clutch is equal to the engine torque (the torque resulting from the explosions) subtracted by the engine internal friction.

Drivlina - Reglering

Reglera moment

Driveline control for gear shifting



Automatic Gear Shifting in Heavy Trucks

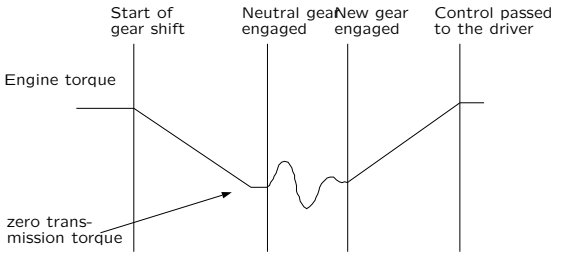
Automatic transmission This approach is seldom used for the heaviest trucks, due to expensive transmissions and problems with short life time. Another drawback is the efficiency loss compared to manual transmissions.

Manual transmission and automatic clutch A quite common approach, which needs an automatic clutch system. This system has to be made robust against clutch wear.

Gear shifting by engine control With this approach the automatic clutch is replaced by engine control, realizing a virtual clutch. The only addition needed to a standard manual transmission is an actuator to move the gear lever. Lower cost and higher efficiency characterize this solution.

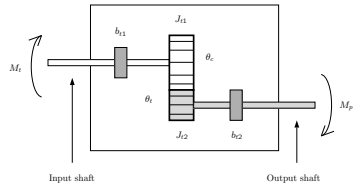
Drivlina - Reglering

Växlingsförlopp



Drivlina - Reglering

Transmission



Simplified model of the transmission with two cogwheels with conversion ratio i_t. The cogwheels are connected to the input and output shafts respectively. The torque transmitted between the cogwheels is the transmission torque, z.

Jämför "Enkelt exempel"

Drivlina - Reglering

Control Criterion

$$\lim_{T\to\infty} \int_0^T z^2 + \eta(u - u_{shift})^2 \tag{8}$$

Utskrivet

$$\begin{aligned} &\lim_{T\to\infty} \int_0^T z^2 + \eta(u - u_{shift}(\dot{\theta}_w, l))^2 \\ =\ &\lim_{T\to\infty} \int_0^T (Mx + Du)^2 + \eta(u - \mu_x\dot{\theta}_w - \mu_l l)^2 \end{aligned} \tag{9}$$

Vad betyder de två termerna?

Drivlina - Reglering

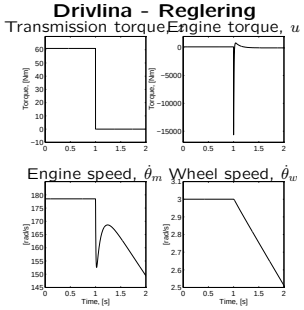
Vad betyder första termen?

Unconstrained Active Damping

$$u = -D^{-1}Mx \tag{10}$$

$z = 0$ is guaranteed.

Drivlina - Reglering



Unconstrained active damping. At t=1 s, a gear shift is commanded and the control law calculates the engine torque such that the transmission torque is driven to zero instantaneously. The oscillations in the transmission torque are damped with an unrealizable large control signal. The wheel speed decreases linearly.

Drivlina - Reglering

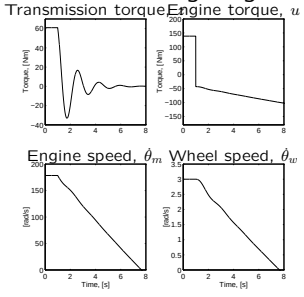
Vad betyder andra termen? $(u - u_{shift})^2$

Gear-Shift Condition

$$u = u_{shift} \tag{11}$$

$z = 0$ ur stelkroppsantagande

Drivlina - Reglering



Control the gear-shift condition. At t=1 s, a gear shift is commanded. The speed dependent realizable control signal drives the transmission torque to zero. Undamped oscillations in the transmission torque increase the time needed to fulfill the goal of controlling the transmission torque to zero.

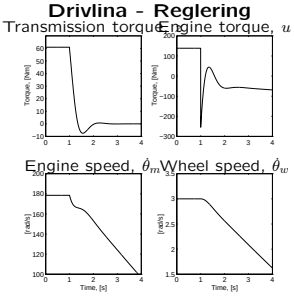
Drivlina - Reglering

Kombinationen

$$\begin{aligned} &\lim_{T\to\infty} \int_0^T z^2 + \eta(u - u_{shift}(\dot{\theta}_w, l))^2 \\ =\ &\lim_{T\to\infty} \int_0^T (Mx + Du)^2 + \eta(u - \mu_x\dot{\theta}_w - \mu_l l)^2 \end{aligned} \tag{12}$$

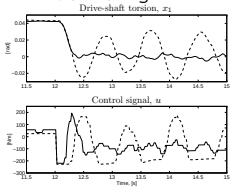
Hur väljer man η?

Drivlina - Reglering



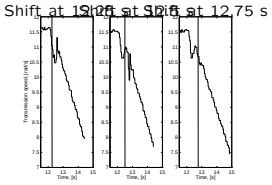
Transmission-torque controller, solving the gear-shift criterion. At t=1 s, a gear shift is commanded. A realizable control signal is used such that the transmission torque is driven to zero, while oscillations are actively damped.

Verifiering - I



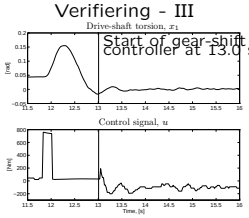
Control signal and drive-shaft torsion when using the gear-shift controller that controls the drive-shaft torsion to zero, started at 12.0 s. Prior to that, the engine has the stationary speed 1900 RPM with gear 1 engaged. In dashed lines, a PI controller is used that gives $x_1 = 0$, but with undamped driveline resonances. The solid lines are extension with the active damping controller.

Verifiering - II



Field trials with start of the gear-shift controller at 12.0 s, all with the same controller controlling the drive-shaft torsion to zero. Engagement of neutral gear is commanded every 0.25 s after the start of the controller, indicated by the vertical lines. The transmission speed is seen when neutral gear is engaged after a delay time. The amplitudes of the transmission speed oscillations after the gear shift are less than 1 rad/s with different signs, which is an acceptable level.

Verifiering - III



Control signal and drive-shaft torsion during field trials with start of the gear-shift controller at 13.0 s. The driveline is oscillating prior to the gear shift due to an engine torque pulse at 11.7 s. The controller controls the drive-shaft torsion to zero with damped resonances despite initial driveline oscillations.

Drivlina - Modellering

Följetongen fortsätter

Enkelt exempel

Illustrerar följande viktiga idéer:

- likhet mellan olika utsignaler
- skillnad mellan olika utsignaler
- förenklat principstudium av poler och nollställen
- momentmodellering
- möjliga förkortningar

Drivlina - Reglering

Förstår ni nu denna figur?