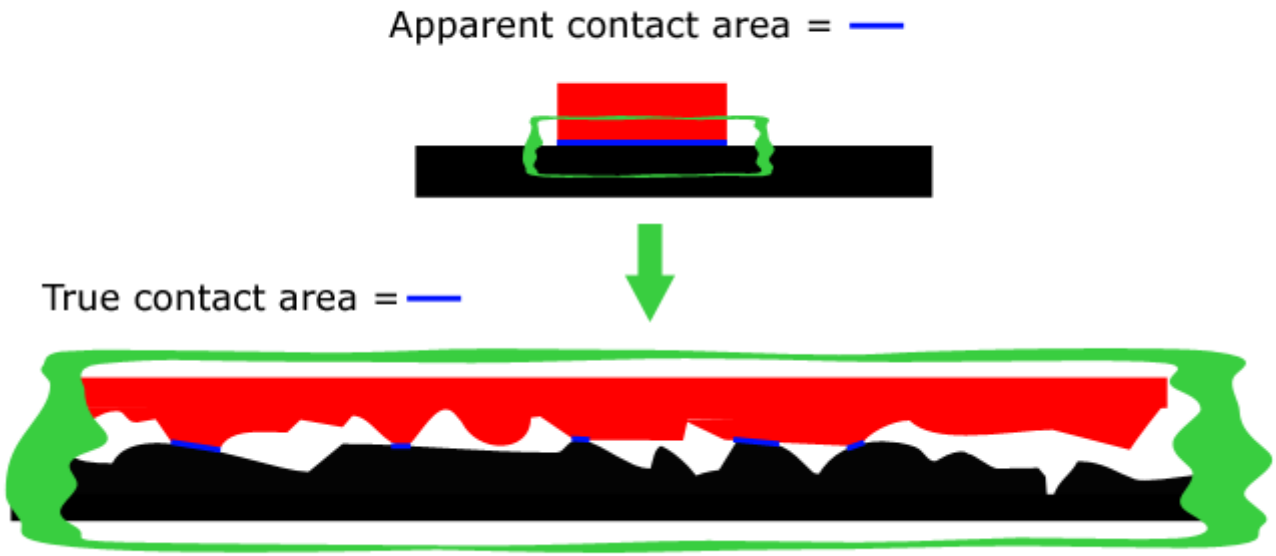
Lecture 12: Friction

- What is friction?
- Why is it important to know about friction for a control engineer?
- Static friction models
- Dynamic friction models

Book: Ch. 5

What is friction?

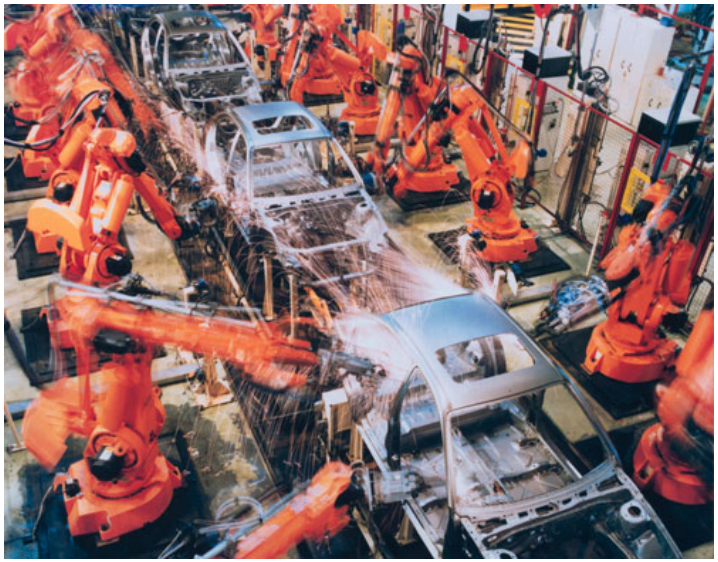


- "The evil of all motion":
  - No matter which direction something is pushed, friction pulls it the other way
- But not all bad: Without friction we cannot move
  - Walking, cycling, driving, flying, …

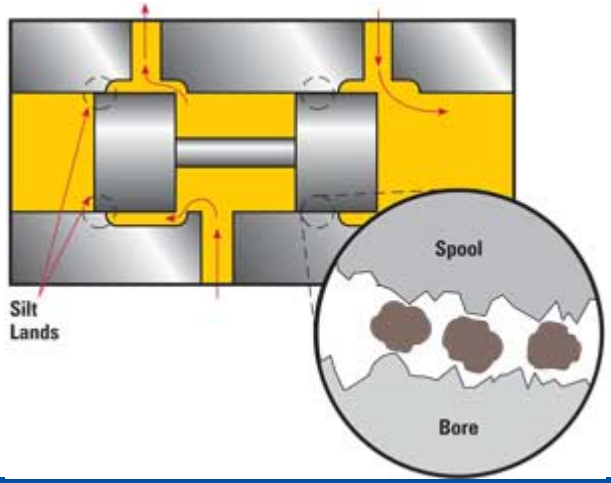
Control systems with friction, I

Friction is a problem for

- Control systems for positioning
  - Electrical and hydraulic actuators
  - Translational or rotational



- In process systems: Valves with friction
  - Often “stiction”



Control systems with friction, II

Friction can be used to control motion

- Electronic stability control (ESC), ”anti-skidding”

Without ESC:

With ESC:

- Also ABS systems exploits friction characteristics

Static friction models

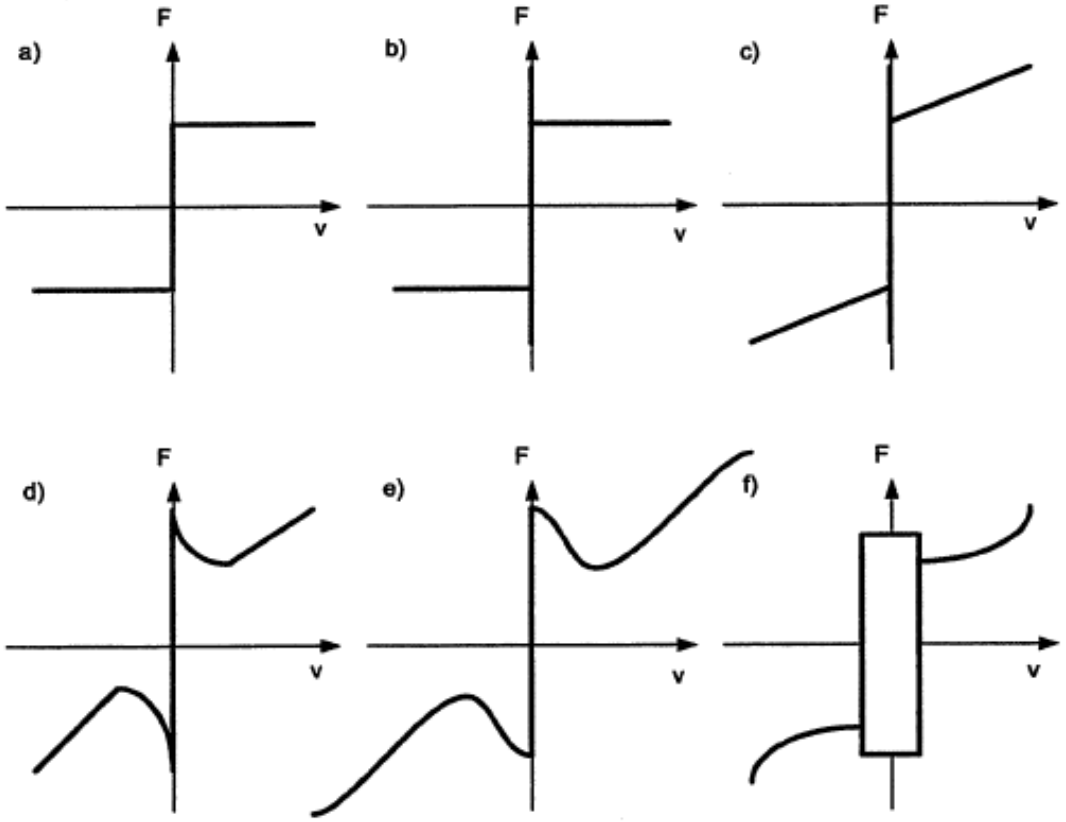
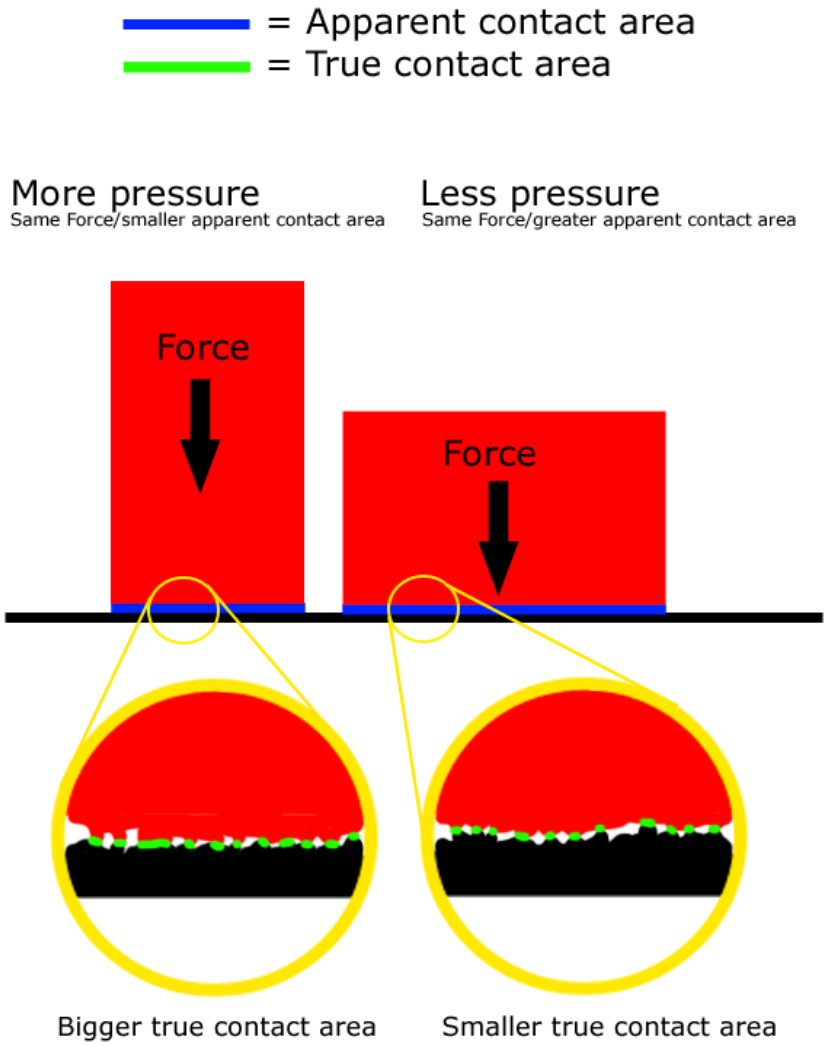


Figure 5.3: Static friction models: a) Colomb friction b) Coulomb+stiction c) Coulomb+stiction+viscous d) Stribeck effect e) Hess and Soom; Armstrong f) Karnopp model

Dry friction is

- Independent of area
  - Da Vinci
- Proportional to normal force
  - Amonton, Euler
- Independent of velocity
  - Coloumb

$$F = \mu F_N$$



Generalized Stribeck curve

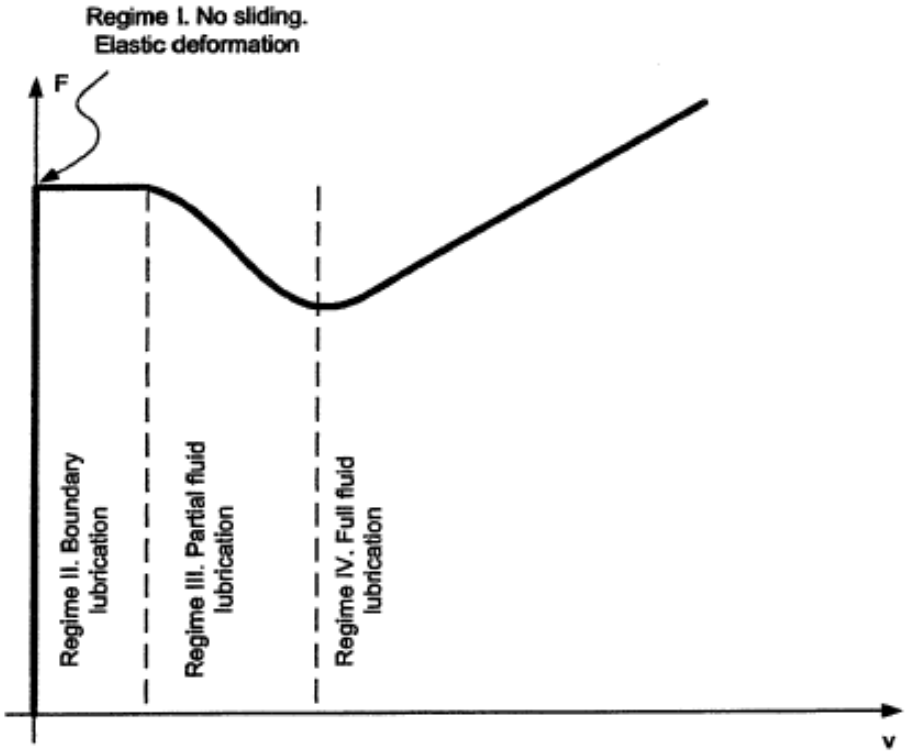


Figure 5.2: The generalized Stribeck curve, showing friction as a function of velocity for low velocities, (Armstrong-Hélouvry et al. 1994).

Dynamic friction models

The Dahl model

$$\frac{\mathrm{d}F}{\mathrm{d}t} = \sigma\left(v - |v|\frac{F}{F_c}\right)$$

The LuGre model

$$F = \sigma_0 z + \sigma_1 \frac{\mathrm{d}z}{\mathrm{d}t} + \sigma_2 v$$

$$\frac{\mathrm{d}z}{\mathrm{d}t} = v - \sigma_0 \frac{|v|}{g(v)} z$$

$$g(v) = F_c + (F_s - F_c)e^{-\left(\frac{v}{v_s}\right)^2}$$

Why dynamic friction models?

- Easier to simulate
- Easier to analyze
- They reproduce (to some extent) dynamic friction phenomena
  - Presliding displacement
    - friction force act as a spring in sticking region
  - Frictional lag
    - Dynamic friction force depends on direction of velocity
  - Varying break-away force
    - Break-away force depends on rate-of-change of applied force

ABS-system – blokkeringsfrie bremser

- Hva er det som gjør at **bremsing**, **gass**, **styring** får bilen til å endre hastighet?

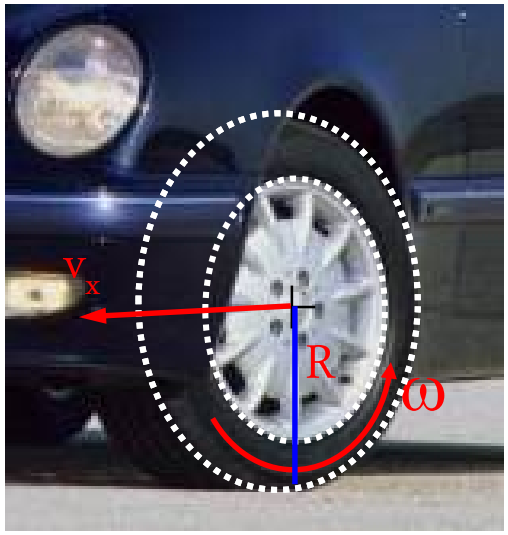
Friksjon mellom hjul og vei

- Hva bestemmer friksjon?
  - Tyngde
  - Underlag og egenskaper ved dekk
    - tørr asfalt, våt asfalt, snø, is
  - **Relativ hastighetsforskjell** mellom bil og hjul
    - langsgående (longitudinal) slipp, side- (lateral) slipp

Slipp – relativ hastighetsforskjell

- I langsretning:

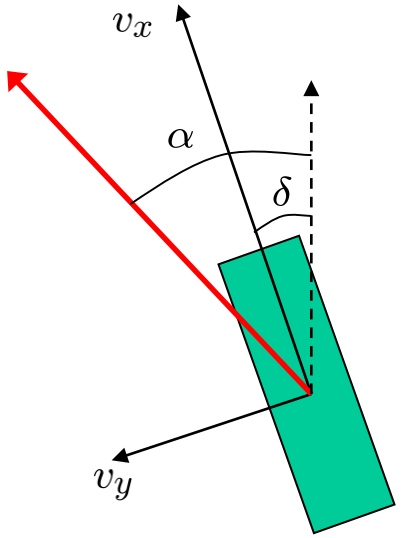
$$\lambda_x := \frac{v_x - R\omega}{v_x}$$



- I sideretning:

$$\lambda_y := \sin\alpha$$

$$\alpha := \delta + \arctan\frac{v_y}{v_x}$$



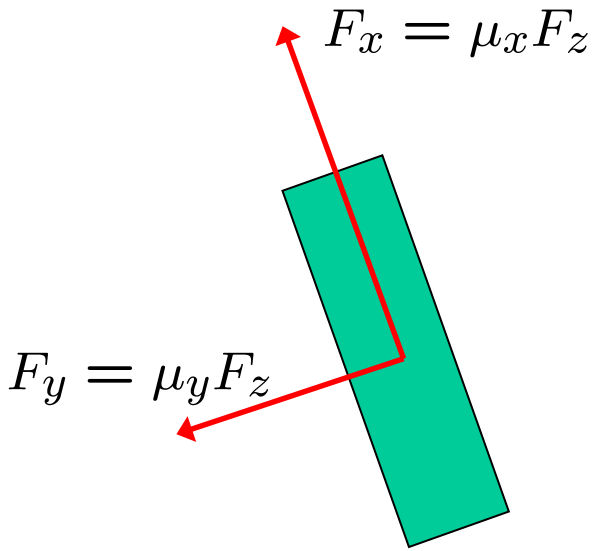
Friksjonskrefter

Coloumbs lov:

- Friksjonskrefter gitt av vertikale krefter og friksjonskoeffisient

- Friksjonskoeffisient gitt av slipp og underlag

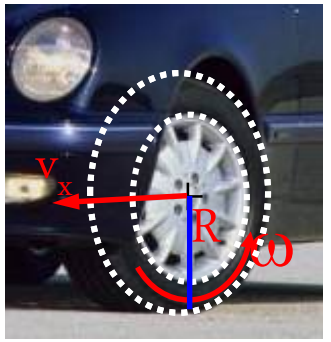
$$\mu_x \approx \mu_x(\lambda_x, \lambda_y, \mu_H)$$
$$\mu_y \approx \mu_y(\lambda_y, \lambda_x, \mu_H)$$

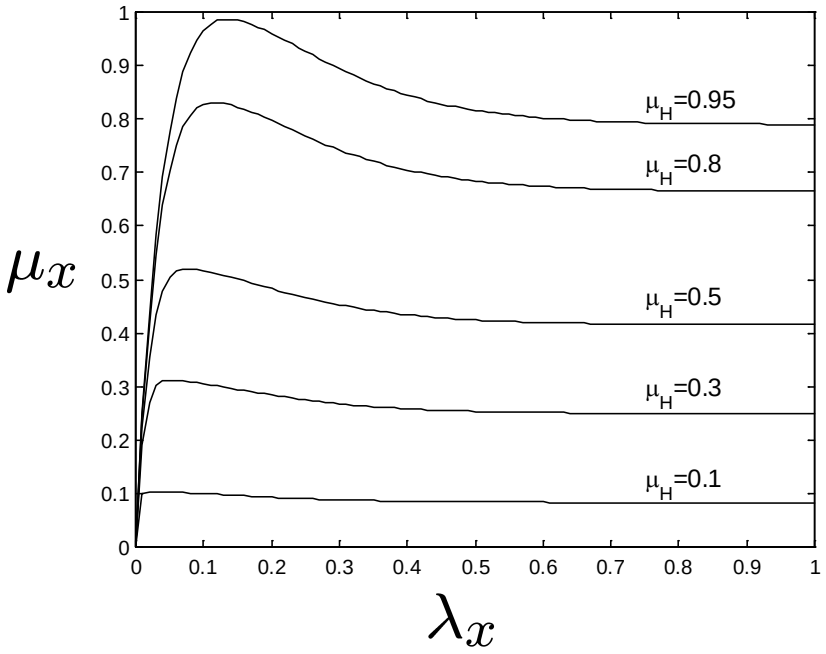


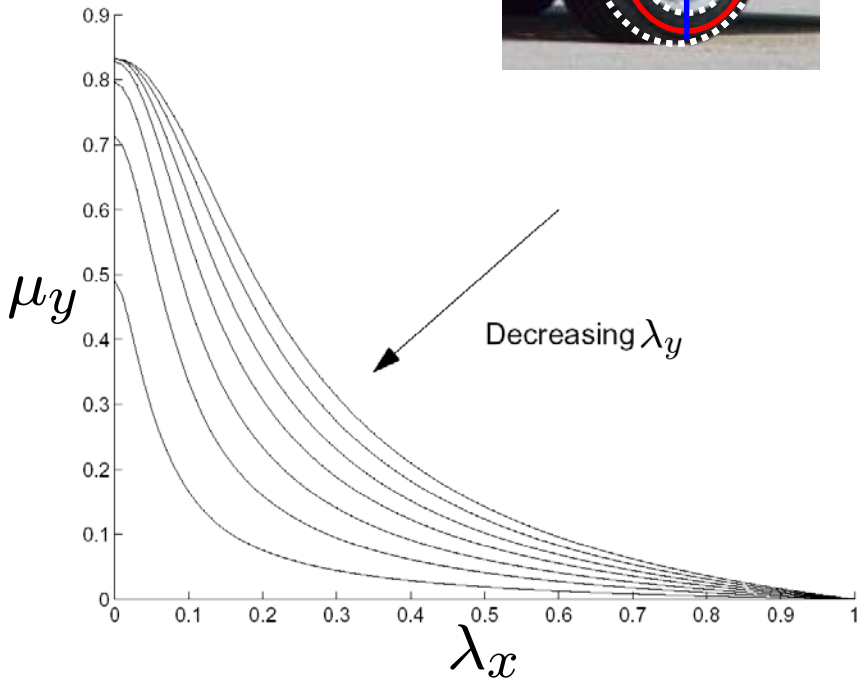
Friksjonskoeffisienter under bremsing

- Bremsing reduserer hjulhastighet i forhold til bilhastighet

$$\lambda_x := \frac{v_x - R\omega}{v_x}$$

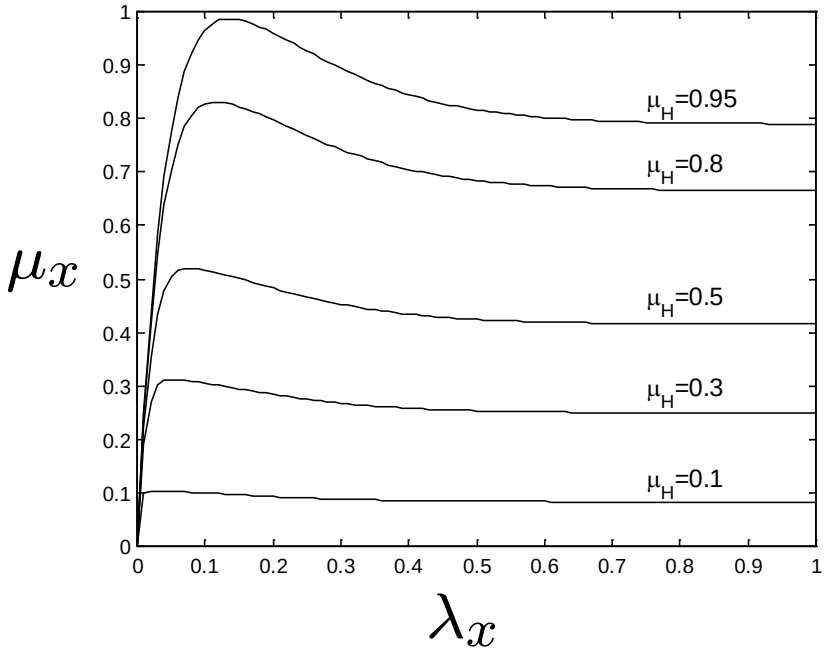


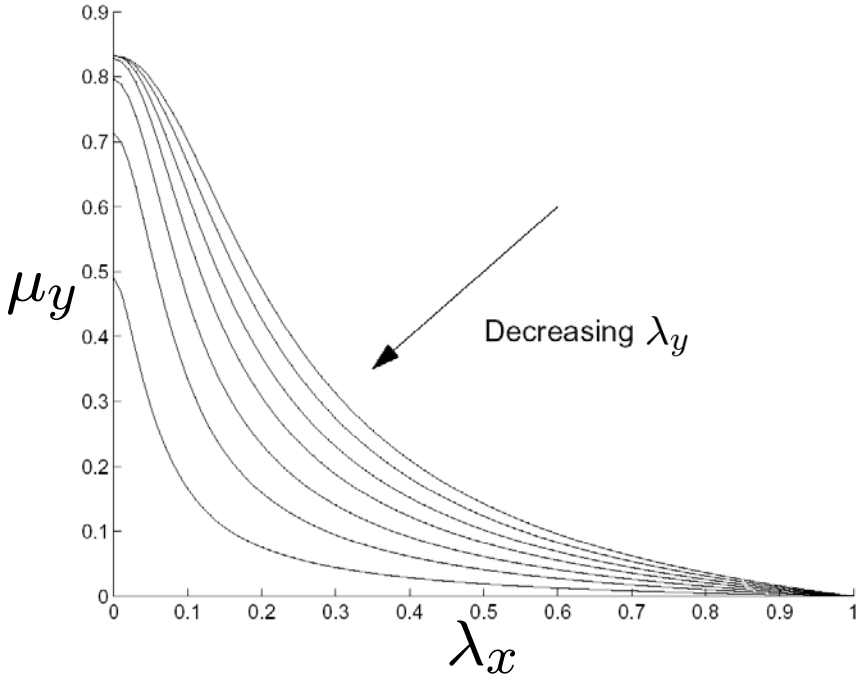




Blokkeringsfrie bremser – ABS

- Ønsker konstant lav slipp under bremsing fordi
  - Det gjør bremsing mest effektivt
  - Kan styre bilen under bremsing





ABS i praksis

Bremselengde:

Unnamanøver: