Non-idealities in Motion Control

Quantization errors in encoders

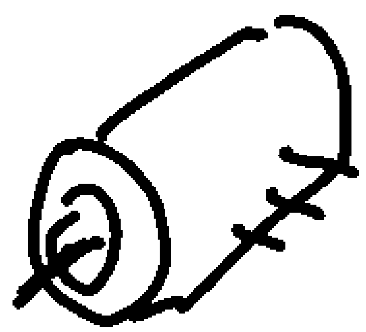
Joint friction

Back-lash

Dead-band

Gearbox

☒ QUANTIZATION ERRORS IN ENCODERS.

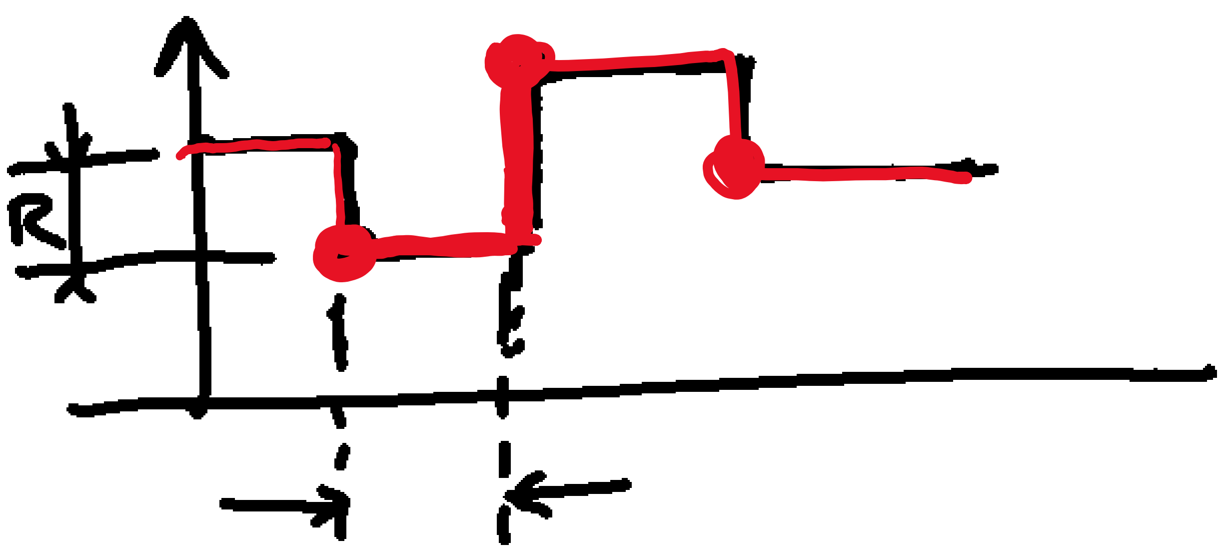


12 bit encoder

$$R = \frac{2\pi}{2^{12}} = \frac{2\pi}{4096} = 0{,}0015 \text{ rad}$$

0,09 deg

RESOLUTION



$T_s = \frac{1}{f_s}$ → Sampling frequency

I When computing velocity with finite differences there is QUANTIZATION NOISE

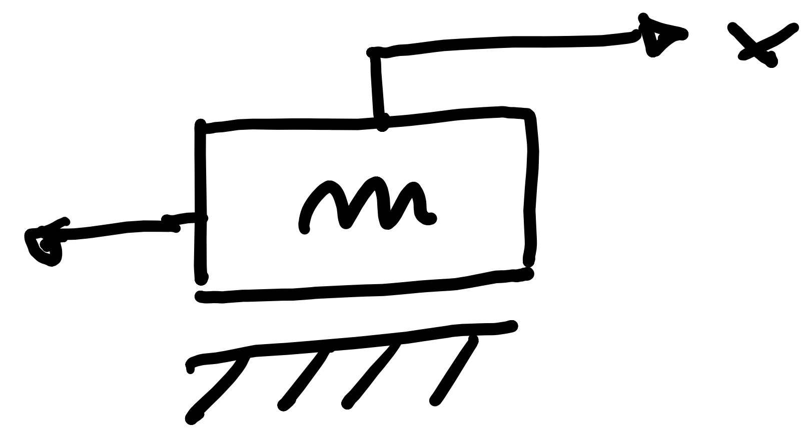
I minimum speed that can be measured

1 change in 1 sampling interval $T_s = 0{,}001$ s

$$\frac{0{,}09}{0{,}001} = 90 \text{ deg/s !}$$

JOINT FRICTION

- bearings
- sliding parts



Frictional force is always opposing motion

$$\boxed{F_f = \underbrace{F_c \, \text{sign}(\dot{x})}_{\text{Coulomb friction}} + \underbrace{B \dot{x}}_{\text{viscous friction}} + \underbrace{F_s \quad (\text{if } \dot{x} = 0)}_{\text{stiction (static friction)}}}$$

Coulomb law:

friction force tangent to contact is related to normal force through friction coeff. μ

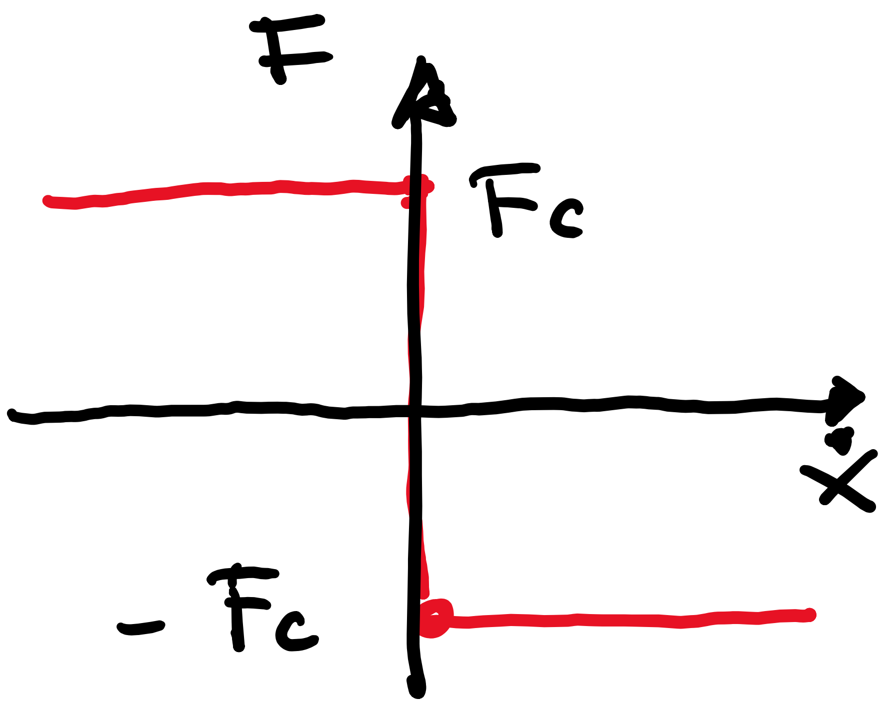
$$F_c = F_t = \mu F_n$$

F_n → normal force

μ → depends on 2 materials in contact

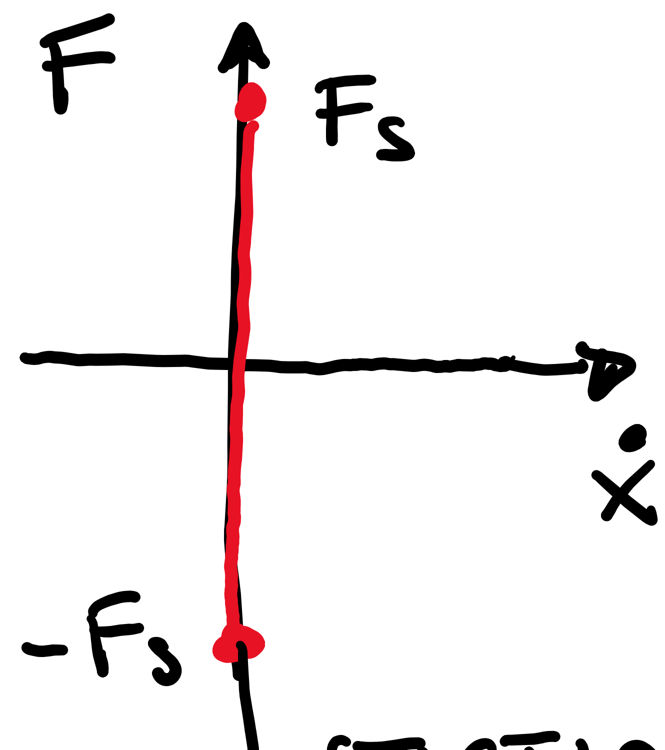
→ independent from speed of slinding

STICTION: called break away friction is like Coulomb friction at ∅ speed and is slightly higher



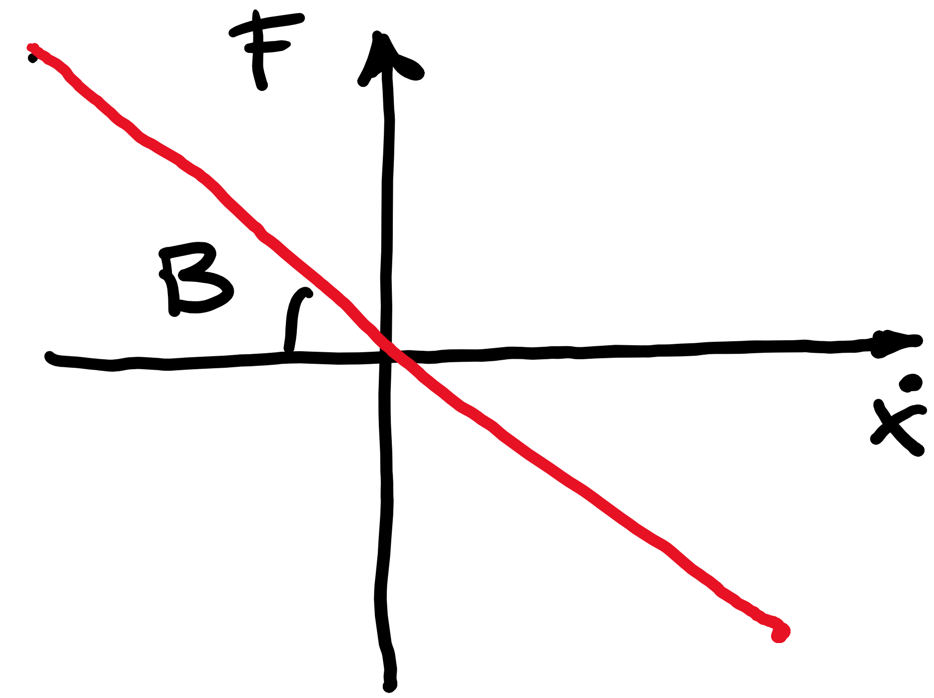
COULOMB

⊕



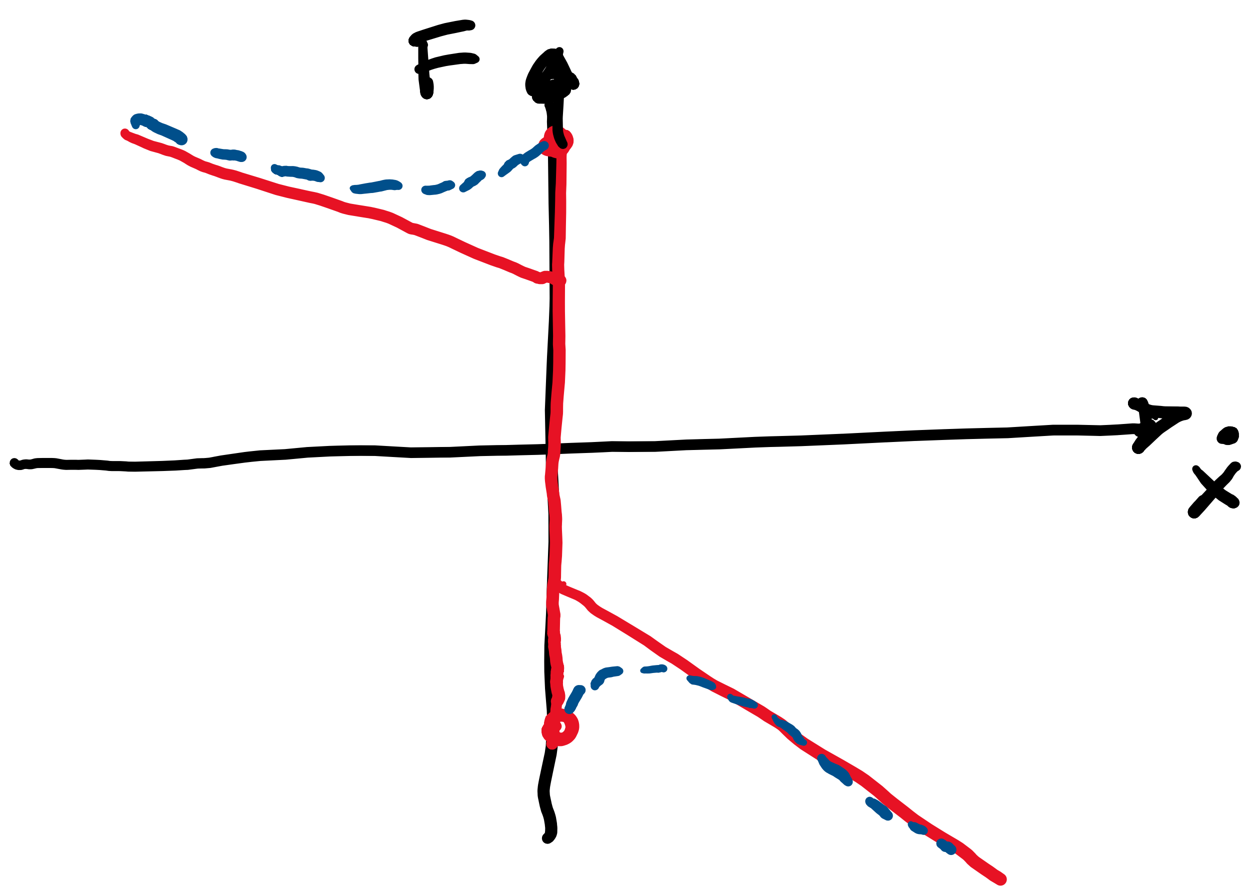
STICTION

⊕



VISCOUS

⊜

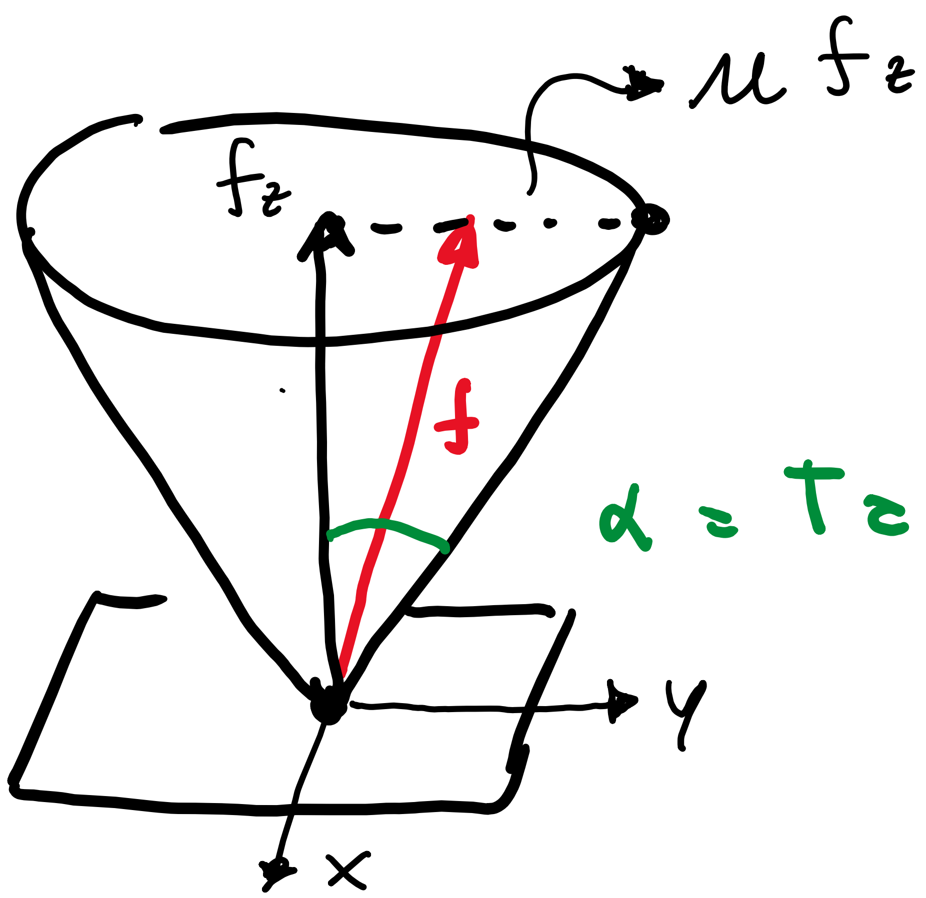


Striebeck effect

positive slope, destabilizing effect / stick-slip

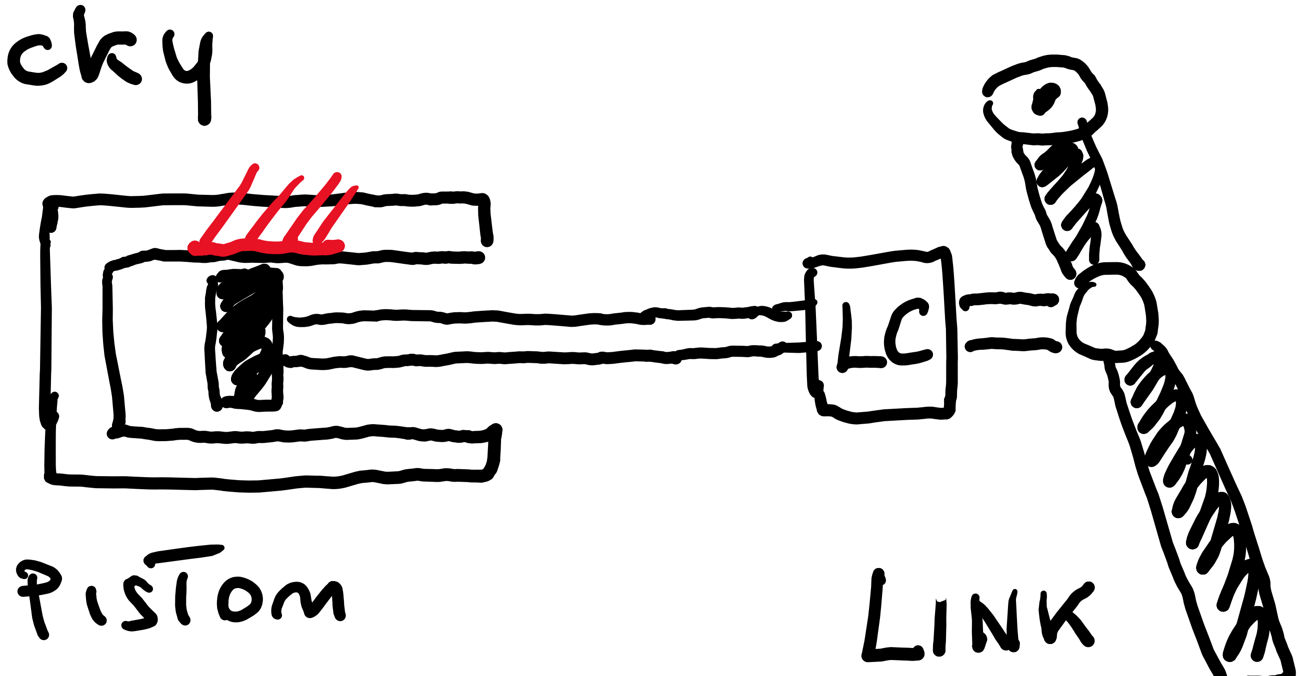
- in This course we neglect sTicTion

- coulomb law can be interpreted as **FRICTION CONE**



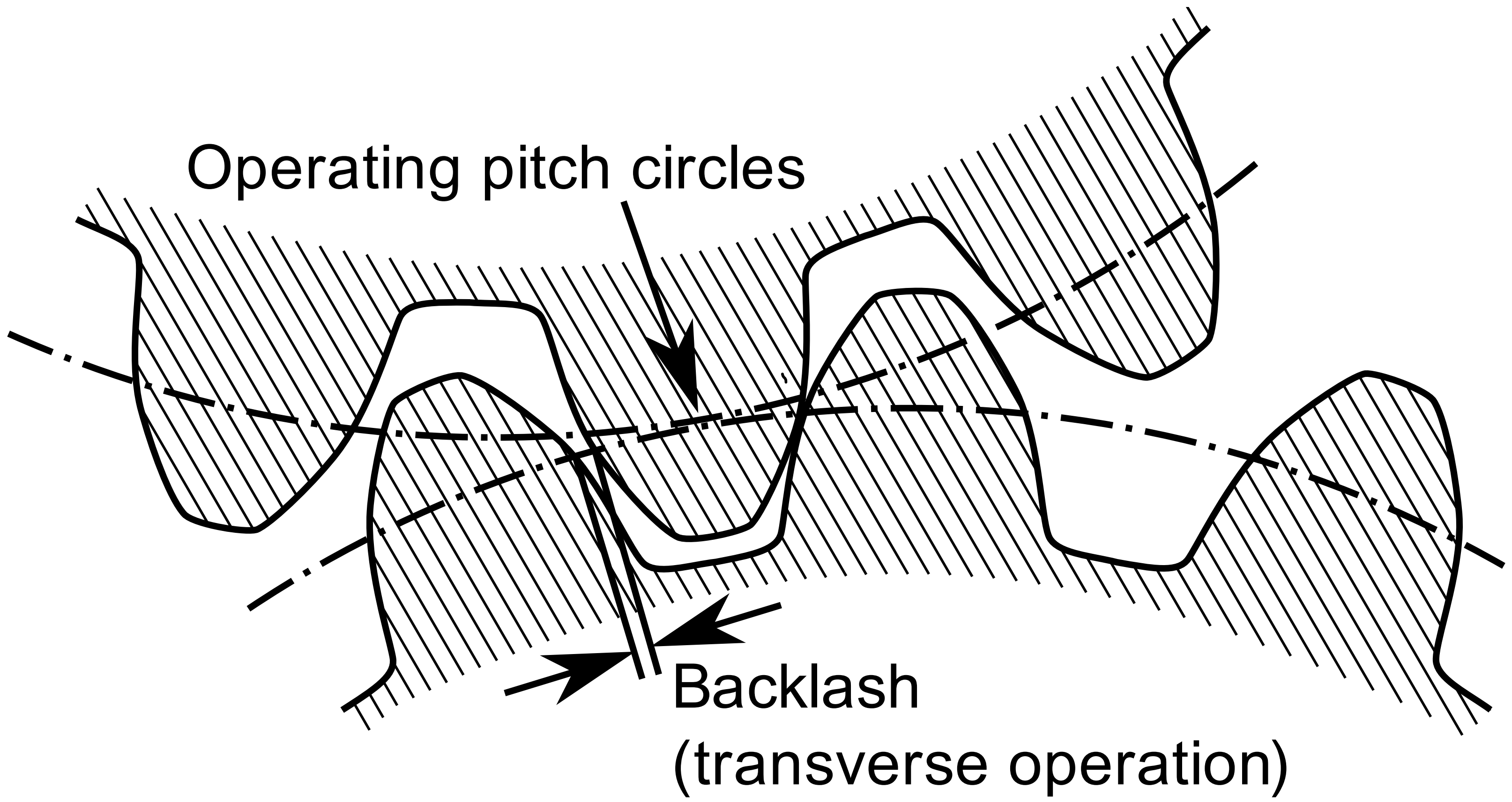
during slippage f is lying on The cone boundary

⊖ identify and compensate friction can be Tricky



is better To locate The load cell link side

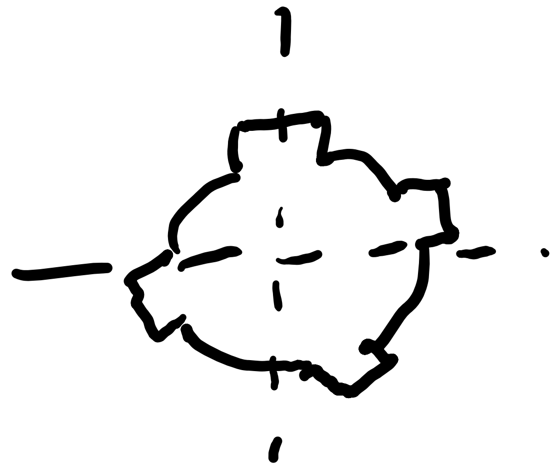
BACKLASH

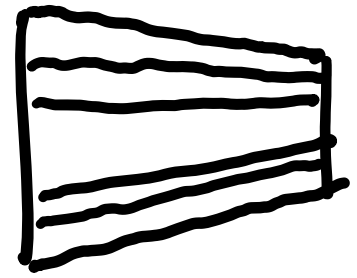


clearance or lost of motion in a mechanism due to gaps between parts (eg Teeth of gear wheel)

⊖ effect on control: limit cycle instabilities, vibrations

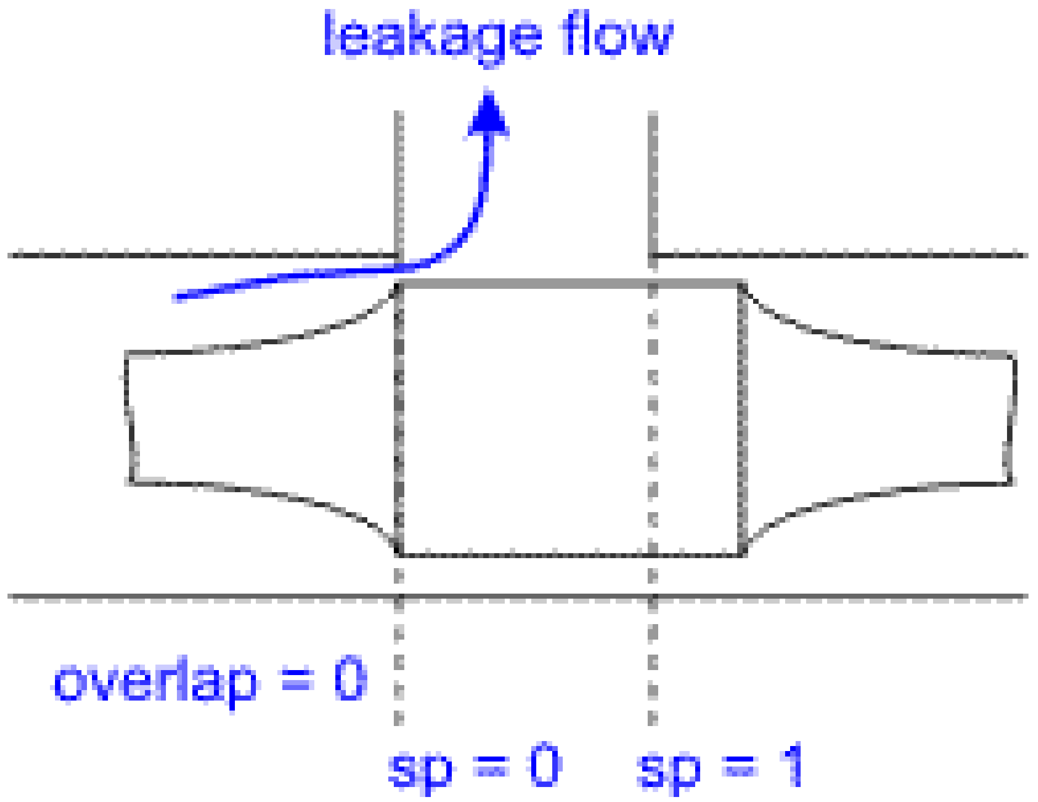
solution: improve mechanical design (e.g. conic fits)

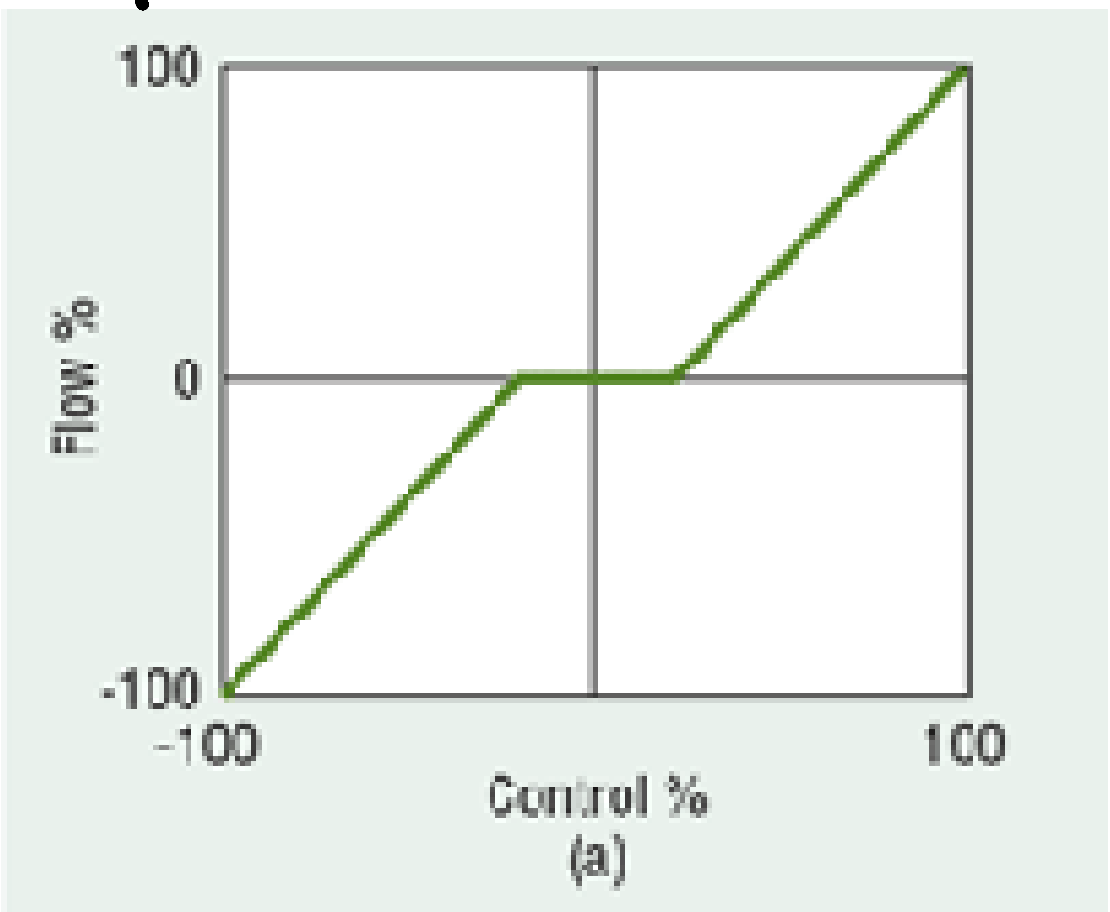




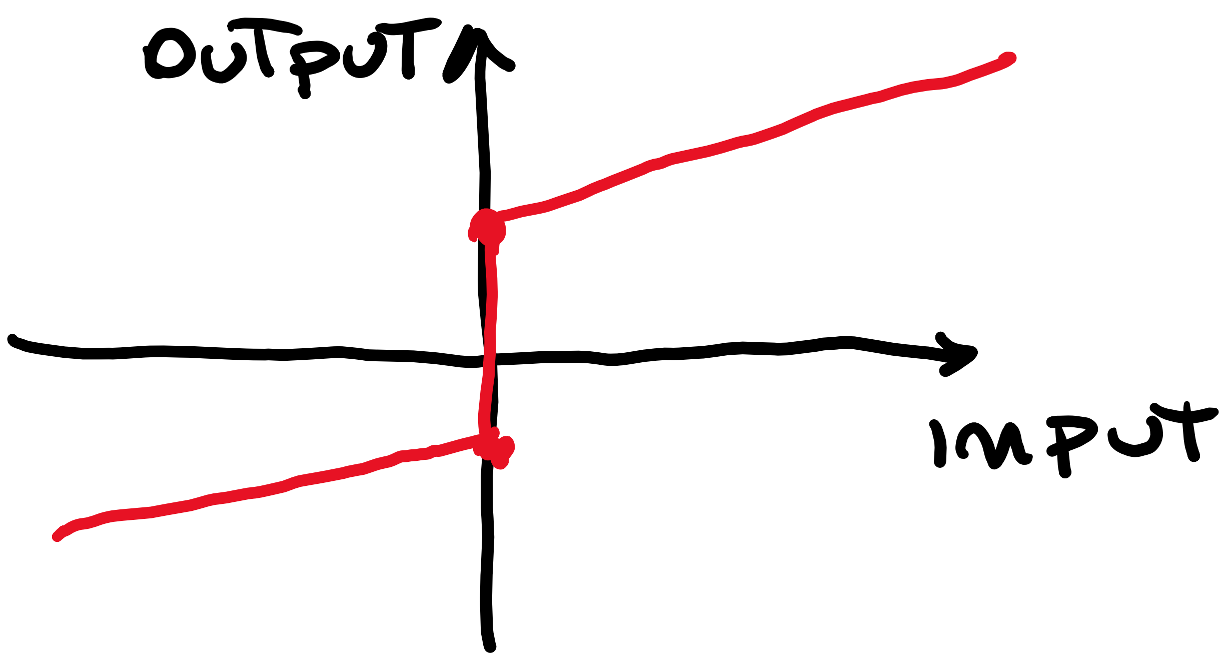
DEAD BAND

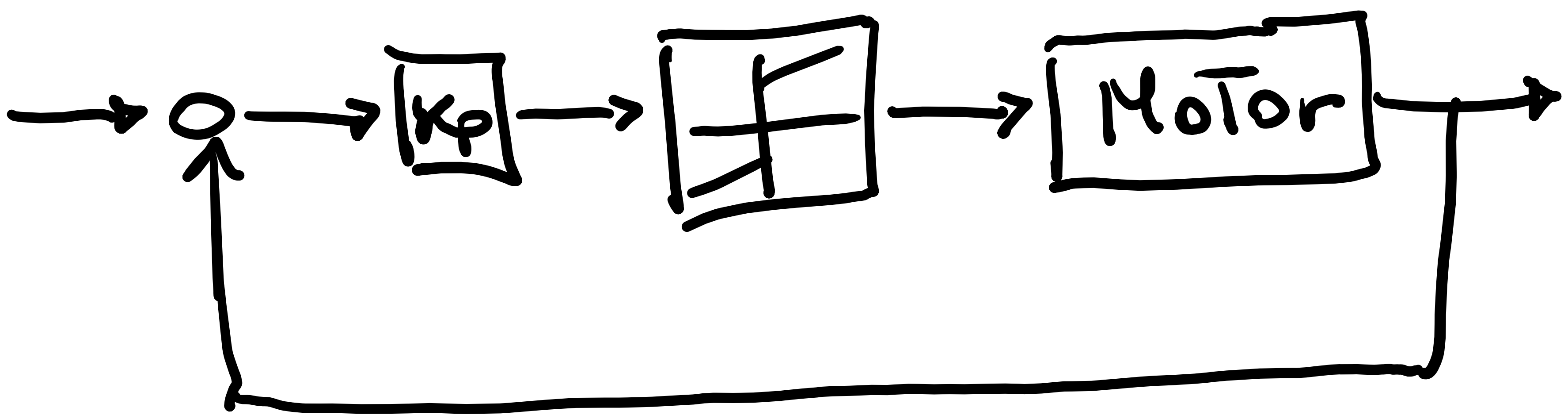
- present in hydraulic valves / motor drivers
- gain is zero for very low inputs





DEAD BAND COMPENSATION

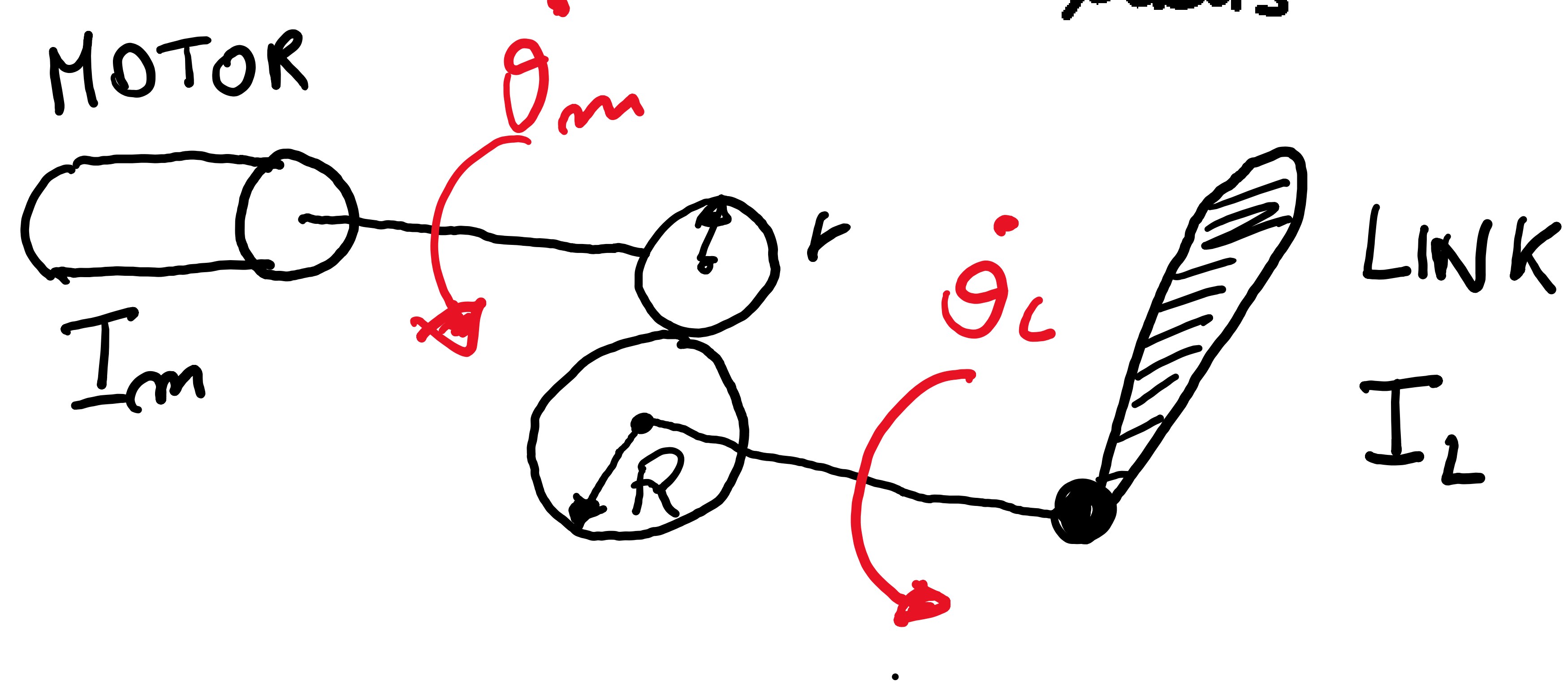




GEAR BOX

- used to amplify the low torque of electrical motors (employ smaller motors → less weight)
  ↓
  fundamental in legged robots

MOTOR



HARMONIC DRIVE GEARBOX

GEAR RATIO $= N = \frac{R}{r}$ (eg 100)

$$P_m \approx \dot\theta_m \tau_m = \dot\theta_L \tau_L = P_L \implies \begin{cases} \dot\theta_L = \dfrac{\dot\theta_m}{N} & \text{Reduces speed} \\ \tau_L = \tau_m N & \text{amplifies Torque} \end{cases}$$

What about inertia?

$$\bar{I}_m = \frac{\tau_L}{\ddot\theta_L} = \frac{\tau_m N}{\dfrac{\ddot\theta_m}{N}} = \frac{\tau_m}{\ddot\theta_m} N^2 = I_m N^2$$

reflected motor inertia on link

Therefore the EFFECTIVE INERTIA link side is

$$I_e = I_L + \bar{I}_m$$

- changes with the configuration
- if $N \uparrow\uparrow$ it can significantly change the Time Response!

RULE OF THUMB

$$\hat{I} = \frac{1}{4}\left(\sqrt{I_{e_{min}}} + \sqrt{I_{e_{max}}}\right)^2$$ geometric average

References:

- Springer Handbook of Robotics - Bruno Siciliano, Oussama Khatib: Forces and Friction (chapter 27.3)
- Control System Design Guide (Fourth Edition), Chapter 12, 2012 - George Ellis: Nonlinear Behavior and Time Variation