CMPUT 399

Intro Robotics & Mechatronics:

Motor Control

Some slides are taken from Northwestern University's "ME 333 Introduction to Mechatronics" by Kevin **Lynch.**

DC motors

- **DC motors: cheap, most common**

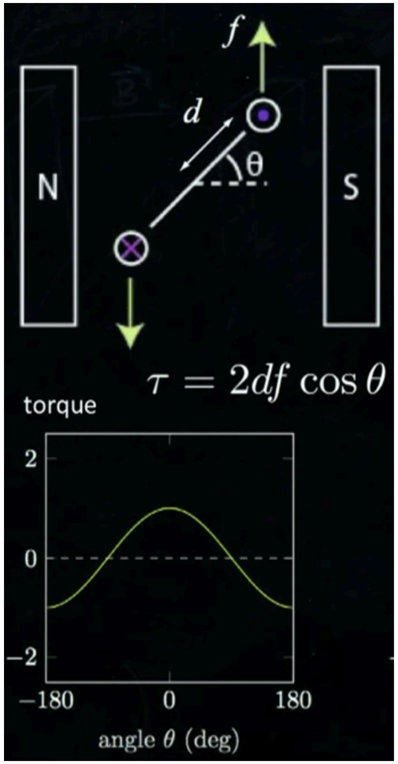
- **DC motor ?**

  https://www.youtube.com/watch?v=LAtPHANEfQo

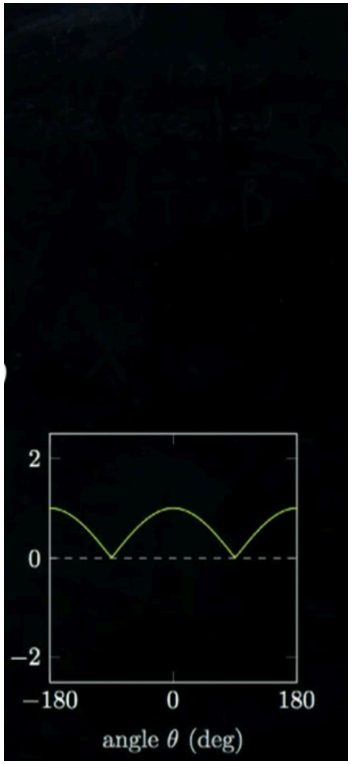
Brushed permanent magnet DC motor

Lorentz' law: $\boldsymbol{F} = l\,\boldsymbol{I} \times \boldsymbol{B}$

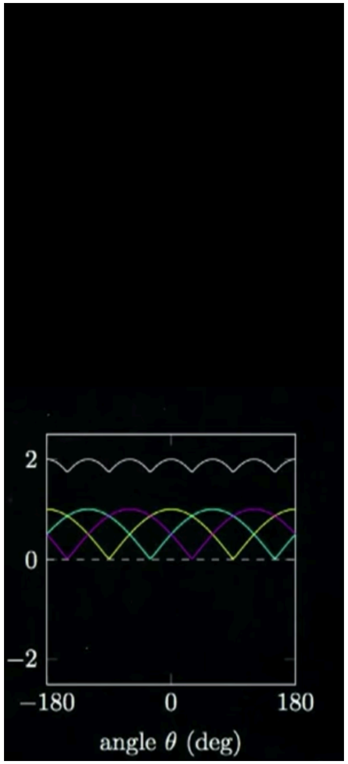
– current flowing through a magnetic field creates a force on the wire carrying the current



Torque changes direction

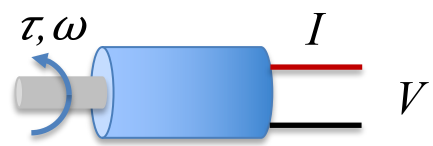


- switch direction of current
- still torque varies



- use 3 loops
- still have torque ripple
- insufficient torque > use coil instead of wire
- commutators to switch current

Model of DC motor Control



Electrical power (input)

- $$I\,V = \tau\,\omega + RI^2 + LI\,\frac{dI}{dt} + \cdots$$ (friction loss, heating, etc.)

Mechanical power (output)

- $$V = \frac{\tau}{I}\,\omega + RI + L\,\frac{dI}{dt}$$

k_t : torque constant : characteristic of motor

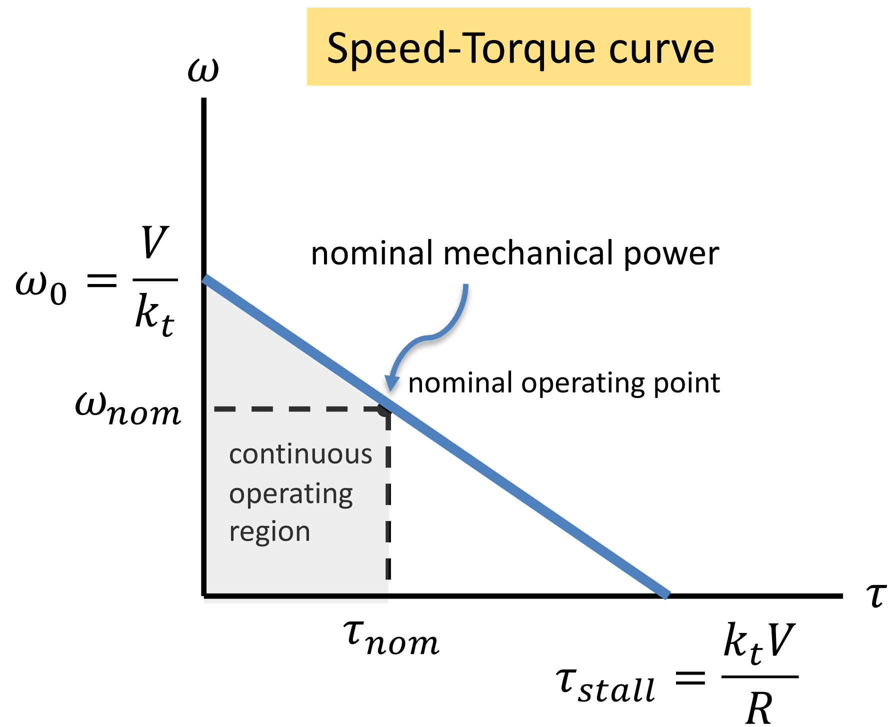
Open-circuit: I=0

- $$V = k_t\,\omega$$

back-emf (electro-motive force) voltage
Opposing the driving voltage

Speed-Torque curve

- $V = k_t\omega + RI + L\frac{dI}{dt}$ (with $L\frac{dI}{dt} \to 0$)
- $\omega = \frac{V}{k_t} - \frac{R}{k_t}\frac{\tau}{k_t}$
- $\omega = \omega_0 - \frac{\omega_0}{\tau_s}\tau$



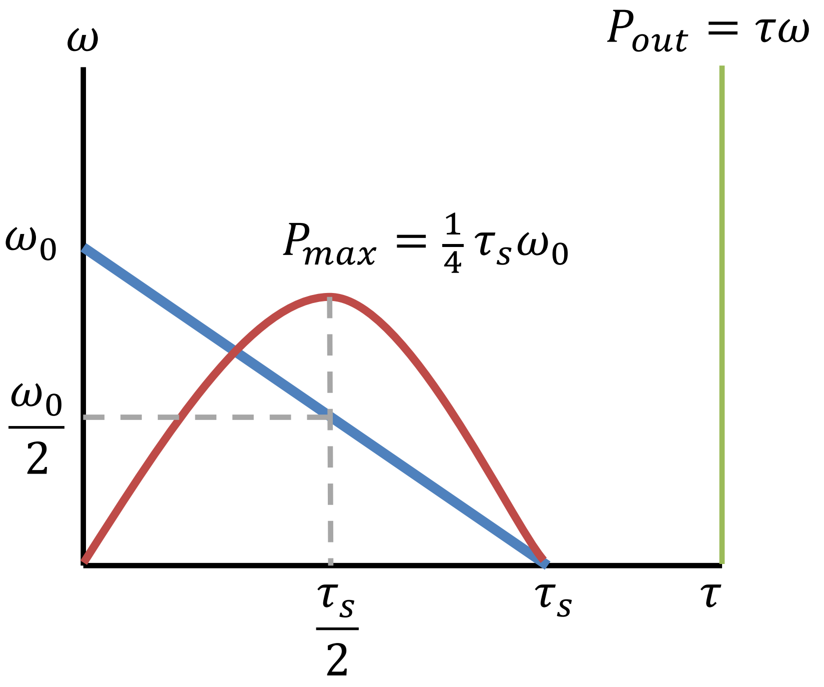
ω_0: no-load speed

τ_s: prevent moving ⇒ large torque ($\tau = k_t I$) ⇒ large current ⇒ (Power=RI^2)⇒ overheating (over long period of time)

Mechanical power in speed-torque curve

- $\omega = \omega_0 - \frac{\omega_0}{\tau_s}\tau$
- $\tau = (\omega_0 - \omega)\frac{\tau_s}{\omega_0}$
- $P_{out} = \tau\omega$

$$= \tau_s\,\omega - \frac{\tau_s}{\omega_0}\omega^2$$



Efficiency = $\frac{P_{out}}{P_{in}} = \frac{\tau\omega}{VI}$ x 100 %

Mechanical power in speed-torque curve

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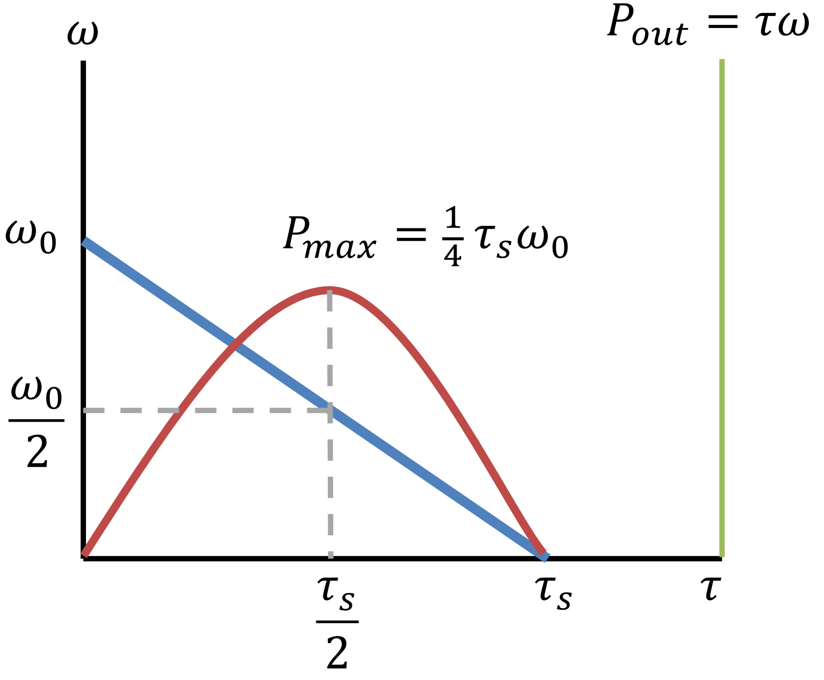

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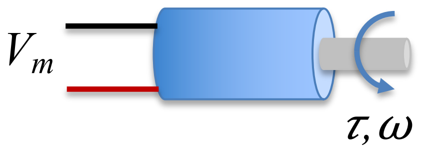
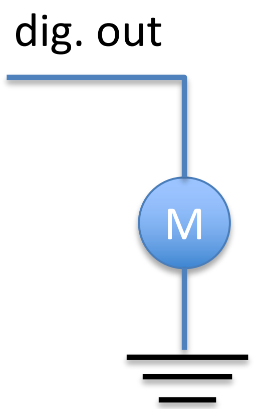
Motor specification (datasheet)

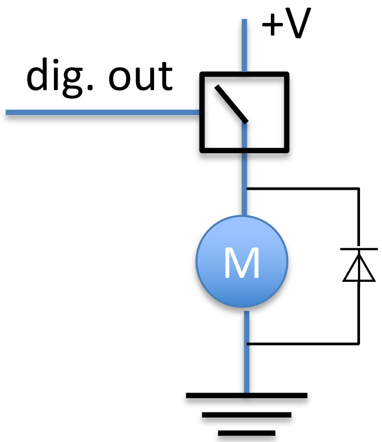
			118742	118743
	Motor Data (10 W)			
	Values at nominal voltage			
1	Nominal voltage	V	9	12
2	No load speed	rpm	5230	4850
3	No load current	mA	38.7	26.3
4	Nominal speed	rpm	4220	3800
5	Nominal torque (max. continuous torque)	mNm	23.9	28.6
6	Nominal current (max. continuous current)	A	1.5	1.24
7	Stall torque	mNm	119	129
8	Starting current	A	7.31	5.5
9	Max. efficiency	%	86	87
	Characteristics			
10	Terminal resistance	Ω	1.23	2.18
11	Terminal inductance	mH	0.115	0.238
12	Torque constant	mNm/A	16.3	23.5
13	Speed constant	rpm/V	584	406
14	Speed / torque gradient	rpm/mNm	44	37.7
15	Mechanical time constant	ms	4.37	4.25
16	Rotor inertia	gcm^2	9.49	10.8

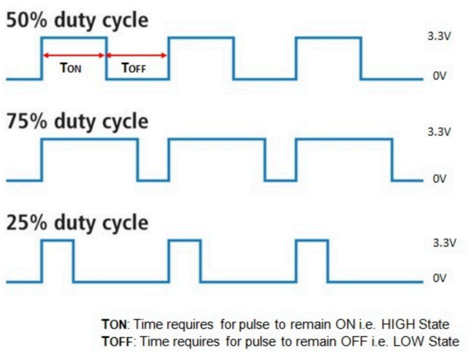
DC motor control

- **Goal**: drive a DC motor with micro-controller









- Low voltage
- Low current

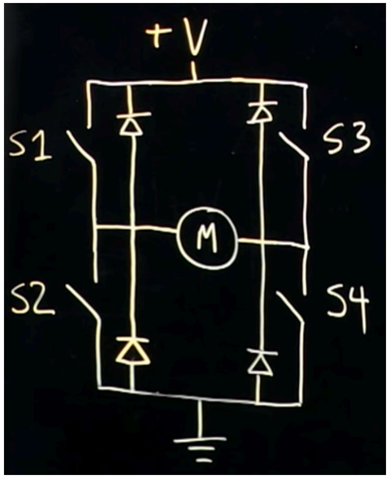
- Add a switch
- $V_m = k_t\omega + IR + L\frac{dI}{dt}$
- Large change of current ⇒ sparks
- use diode (flyback diode)
- current decay to zero exponentially
- **enable us to turn motor on/off**

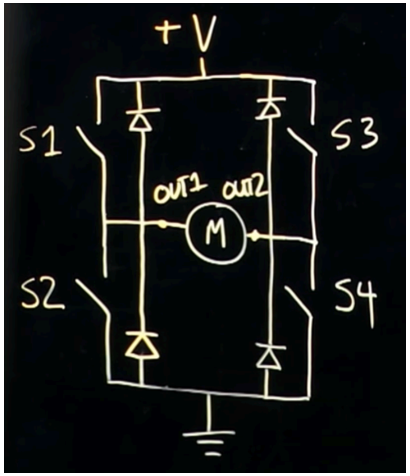
- to control speed we use PWM
- PWM controls duty cycle of closing/opening the switch
- 10 KHz $\leq$ f $\leq$ 40 KHz
- **enable us to control speed in 1-direction**

- **bi-directional >>> H-bridge**

DC motor control

- **H-bridge**



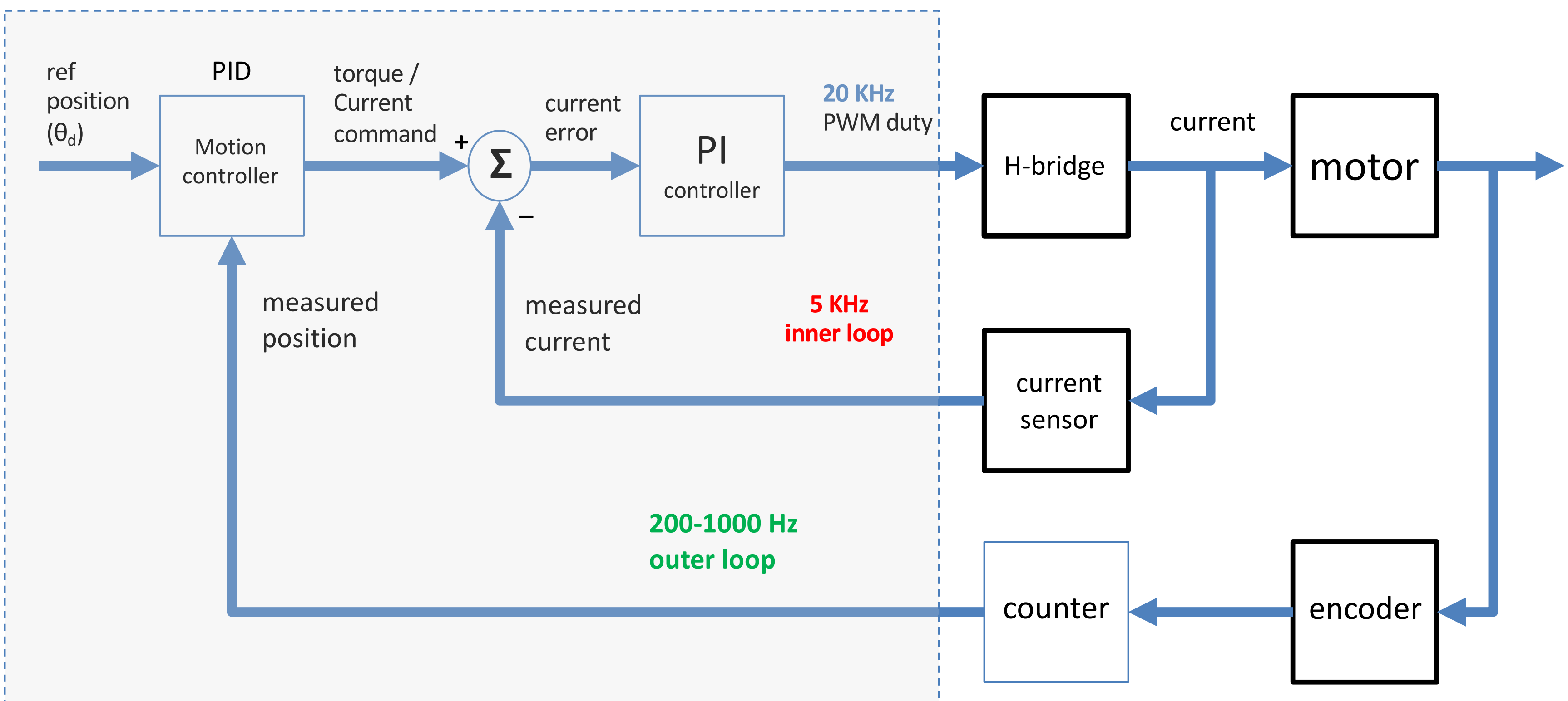


closed switches:
S1 , S4 : forward
S2 , S3 : reverse
S1 , S3 : brake
S2 , S4 : brake
one/none: coast

OUT1	**OUT2**	
off	**off**	**coast**
H	**L**	**forward**
L	**H**	**reverse**
shorted		**brake**

Motor Control System

- Complete motor control system



BLDC motors

- **Brushless DC (BLDC) motor :**

  https://www.youtube.com/watch?v=bCEiOnuODac