The Physics of Motor Performance

What is importance of motor performance?

Maximizing Motor Power

Relationship Between Speed and Torque

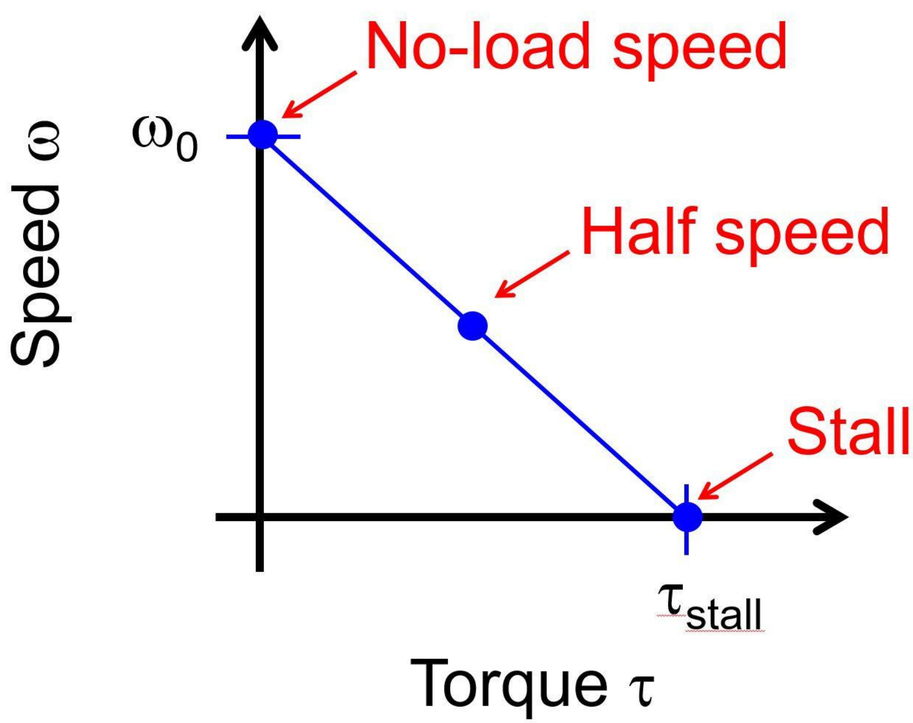
If the motor has no torque it spins at no-load speed, w_0

No torque= maximum speed

If the motor is loaded with the stall torque t_{stall} or more, the motor will stop

All torque= no speed

Speed vs. Torque is Linear



This is at one voltage

y = mx+b

y = speed, omega

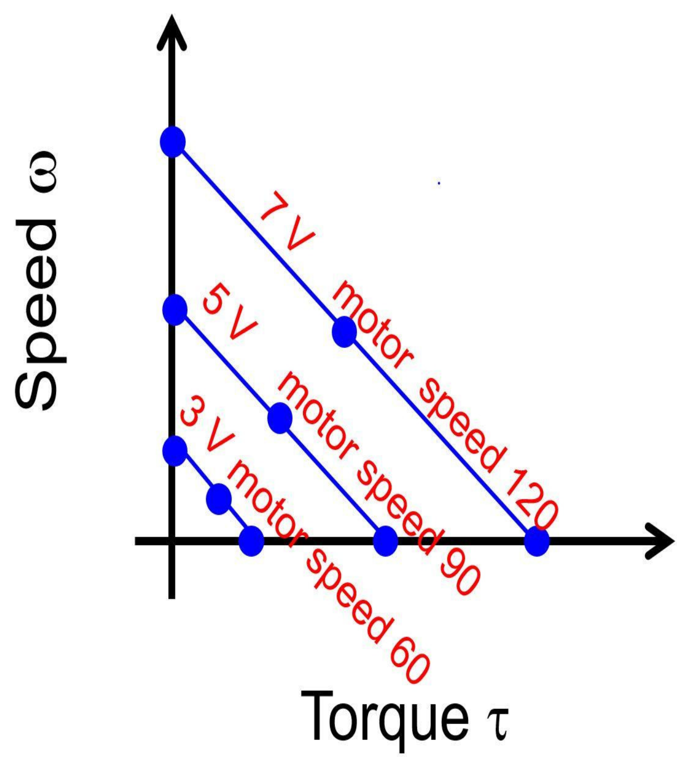
x = torque, tau

m = slope = rise/run = - no-load speed/stall torque

b = no-load speed

$$\boxed{\omega = \frac{-\omega_0}{\tau_{stall}} \cdot \tau + \omega_0}$$

Speed vs. Torque Depends on Voltage



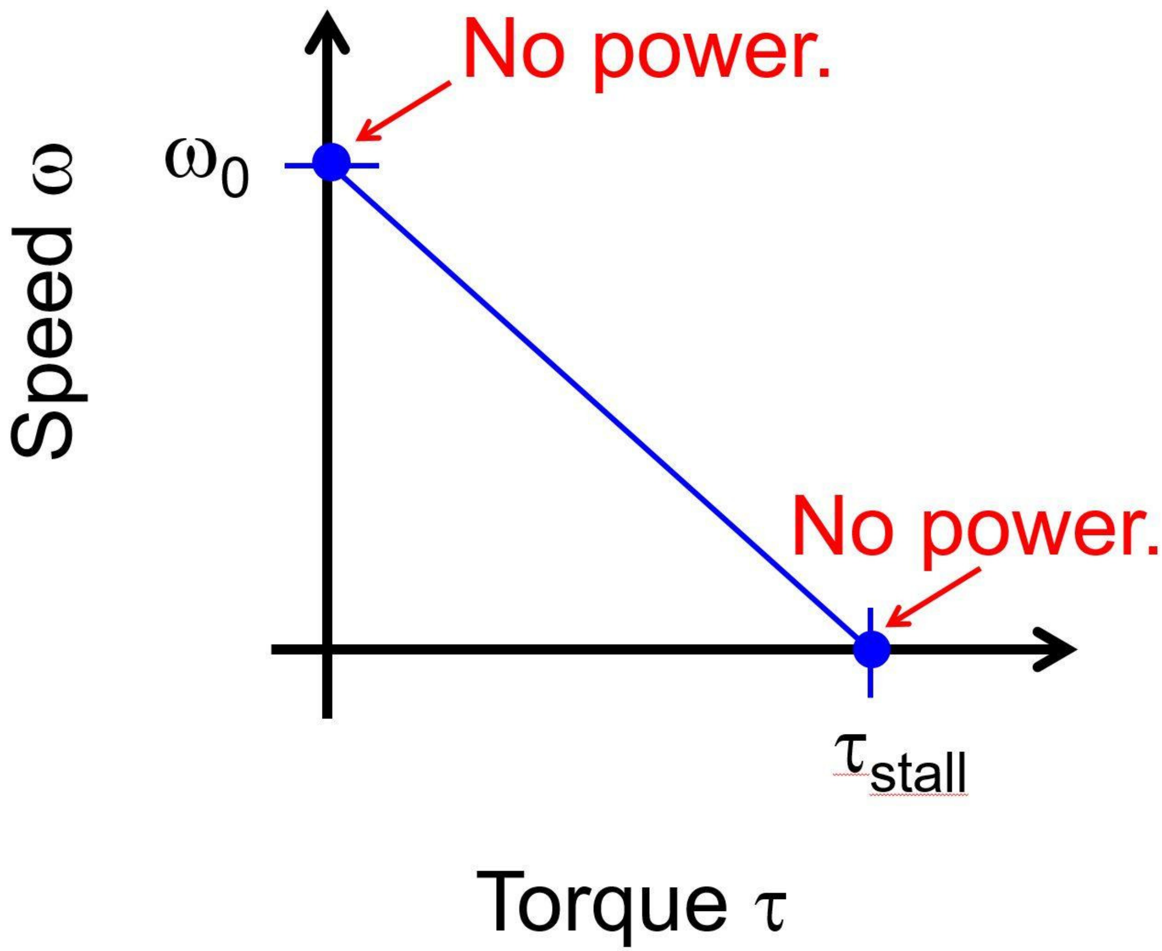
Three different speed-versus-torque graphs at different voltages

Lower voltage- no-load speed and stall torque are smaller

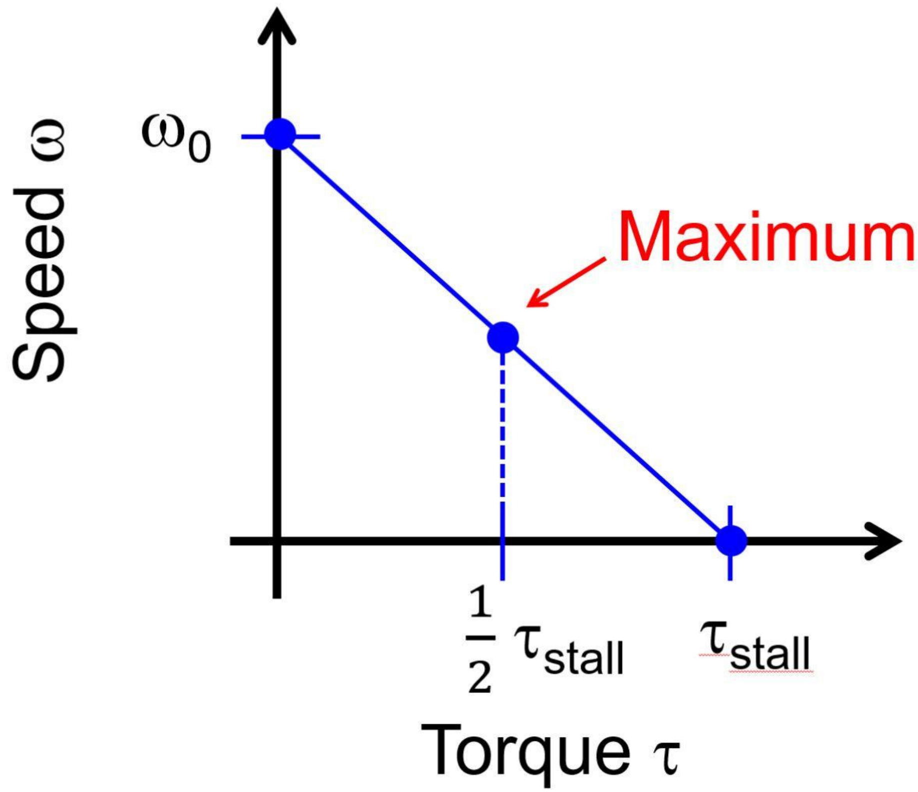
More torque means the slower it will go

Power= Torque x Angular Speed

$$P = \tau \cdot \omega$$


No power.
ω_0
Speed ω
No power.
τ_{stall}
Torque τ

Maximum Power at Half Stall Torque



Full power at half the stall torque

Multiplying each side by Torque

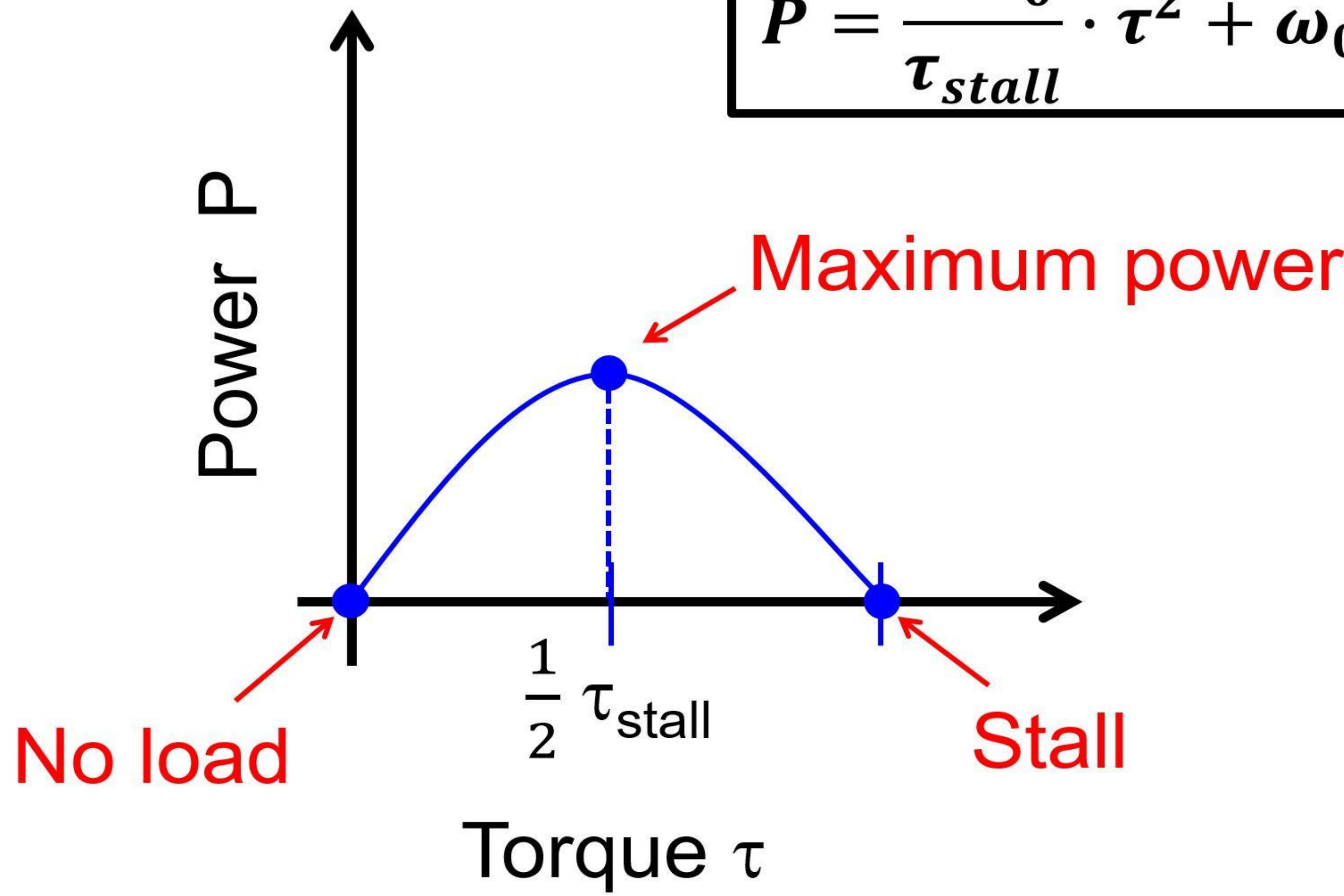
$$\omega = \frac{-\omega_0}{\tau_{stall}} \cdot \tau + \omega_0$$

$$P = \left[\frac{-\omega_0}{\tau_{stall}} \cdot \tau + \omega_0\right](\tau)$$

$$P = \frac{-\omega_0}{\tau_{stall}} \cdot \tau^2 + \omega_0 \tau$$

Maximum Power at Half Stall Torque

$$\boxed{P = \frac{-\omega_0}{\tau_{stall}} \cdot \tau^2 + \omega_0 \tau}$$



Gear Ratio

$$\frac{GR}{1} = \frac{n_{out}}{n_{in}} = \frac{d_{out}}{d_{in}} = \frac{\omega_{in}}{\omega_{out}} = \frac{\tau_{out}}{\tau_{in}}$$

Gear Ratio

Variables to know

n = number of teeth

d = diameter

w = angular velocity (speed)

t = torque

$$\frac{GR}{1} = \frac{n_{out}}{n_{in}} = \frac{d_{out}}{d_{in}} = \frac{\omega_{in}}{\omega_{out}} = \frac{\tau_{out}}{\tau_{in}}$$

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HD HEX MOTOR

REV-41-1301

- No-Load Current: 400mA
- Stall Current: 8.5A
- Max Output Power: 15W

40:1 SPUR GEARBOX OPTION

- Free Speed: 150 rpm (15.7 rad/s)
- Stall Torque: 594.7 oz-in (4.2 Nm)

20:1 SPUR GEARBOX OPTIONWEIGHT: 350G

- Free Speed: 300 rpm (31.4 rad/s)
- Stall Torque: 297.4 oz-in (2.1 Nm)

SMART ROBOT SERVO

REV-41-1097

SPECIFICATIONS

- Speed: 0.14 s/60° (at 6V)
- Stall Torque: 13.5 kg-cm / 187.8 oz-in (at 6V)

$$\frac{GR}{1} = \frac{n_{out}}{n_{in}} = \frac{d_{out}}{d_{in}} = \frac{\omega_{in}}{\omega_{out}} = \frac{\tau_{out}}{\tau_{in}}$$

CORE HEX MOTOR

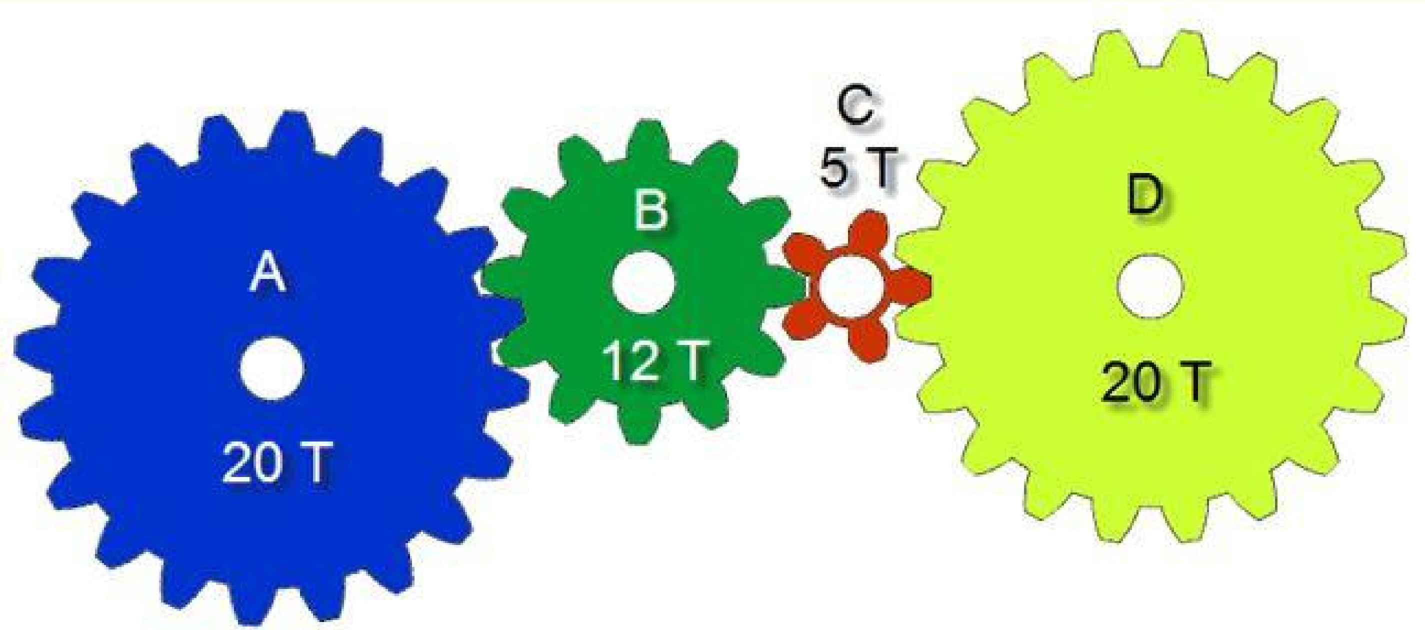
REV-41-1300

SPECIFICATIONS

- Free Speed: 125 RPM
- Stall Torque: 3.2 N-m

NeveRest Classic Motor ONLY (am-3104)

- No Load Free Speed: 6600 RPM
- Stall Torque: 8.75 oz-in



Variables to know

n = number of teeth

d = diameter

w = angular velocity (speed)

t = torque

What is the gear ratio between gears A and B? $\frac{GR}{1} = \frac{n_{out}}{n_{in}} = \frac{12}{20} = \frac{.6}{1}$

What is the gear ratio between gears B and C? $\frac{GR}{1} = \frac{n_{out}}{n_{in}} = \frac{5}{12} = \frac{.42}{1}$

What is the gear ratio between gears C and D? $\frac{GR}{1} = \frac{n_{out}}{n_{in}} = \frac{20}{5} = \frac{4}{1}$

Picking a Gear Ratio

Picking a Gear Ratio

Step 1. What is the stall torque?

$$\tau_{stall} = d \times F_{\perp}$$
$$= (3 \text{ in.})(1.4 \text{ lb})$$
$$= 4.2 \text{ lb·in.}$$

Step 2. At what torque will the motor deliver maximum power?

$$\tau_{maxPower} = ½\, \tau_{stall}$$
$$= ½\, (4.2 \text{ lb·in.}) = 2.1 \text{ lb·in.}$$

Step 3. What torque is the motor applying? (when you are actually using the motor)

$$\tau_{out} = d \times F_{\perp}$$
$$= (2 \text{ in.})(0.2 \text{ lb})$$
$$= 0.4 \text{ lb·in.}$$

Step 4. What gear ratio would make the motor deliver maximum power?

$$GR = \frac{\tau_{out}}{\tau_{in}} = \frac{0.4 \text{ in.} \cdot \text{lb}}{2.1 \text{ in.} \cdot \text{lb}}$$

$$= 0.19 \doteq \frac{12 \text{ teeth}}{60 \text{ teeth}}$$

Weight Budget

$$\frac{Power}{Weight} = \text{Weight Budget}$$

POWER TO WEIGHT RATIO: Weight Budget

Amount of torque a robots drive system provides compared to the weight of the robot

Ratio should be even

$$\frac{Power}{Weight} = \frac{\frac{\text{joules}}{\text{second}}}{\text{Newton}} = \text{meter/second}$$