Lab 10 (associated with Hw 10): Feedback control of a motor

The purpose of this lab is to observe the effects of feedback control and to develop physical intuition for various feedback control constants.

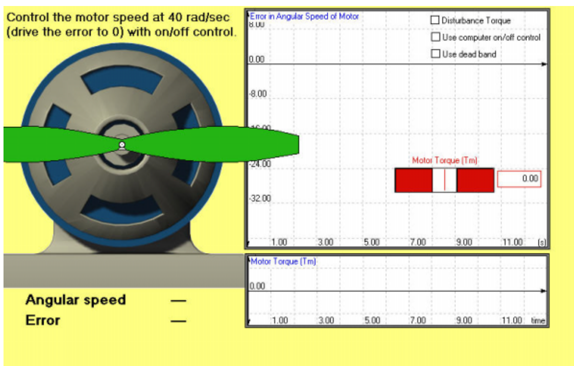
The ODE governing the motion of the system depicted below is:

$$I * \dot{\omega} \;=\; T_m \;+\; T_{\text{disturbance}}$$

- I is the moment of inertia of the motor and its attachments about the motor's axis
- ω is the motor's angular speed (quantity to be controlled)
- T_m is the torque on the motor from the current passing through it
  (this problem tries various ***feedback control laws*** for T_m)
- $T_{\text{disturbance}}$ is the torque on the motor from unmodeled disturbances
  (e.g., viscous friction, Coulomb friction, loads, etc).

Lab 10.1 On/off (bang-bang) feedback control of motor speed.

To begin this problem, double-click on the file `MotorControlWithOnOffAndDeadBand.wm2d`.



The point of this problem is to control ω using an ***on/off feedback control*** for T_m.

To answer each question with Working Model, click the **Reset** button (if necessary) and click and drag the slider that controls the motor torque T_m and try to keep the motor spinning at $\omega = 40 \frac{\text{rad}}{\text{sec}}$.

To start the simulation, click the **Run ▶** button, and to stop it, click the **Stop ▮▮** button.

(a) Using your eyes (sensors) and the motor torque slider (actuator), try to control the motor's angular speed ω at 40 $\frac{\text{rad}}{\text{sec}}$ so that $|\widetilde{\omega}|$, the magnitude of the error is less than 0.5 $\frac{\text{rad}}{\text{sec}}$.
It is **easy/difficult/impossible** to control $|\widetilde{\omega}|$ to less than 0.5 $\frac{\text{rad}}{\text{sec}}$.

(b) Click the **Reset** button and then click the box labeled "Disturbance torque".
Again, try to control $\omega = 40 \frac{\text{rad}}{\text{sec}}$ to within $\pm 0.5 \frac{\text{rad}}{\text{sec}}$.
It is **easy/difficult/impossible** to control $|\widetilde{\omega}|$ to less than 0.5 $\frac{\text{rad}}{\text{sec}}$.

(c) Click the **Reset** button and then click the box labeled "Use computer on/off control". This instructs Working Model to implement the following on/off control system

$$\begin{array}{ll} \text{if}(\ \omega{=}40\ ) & T_m{=}0 \\ \text{else if}(\ \omega < 40\ ) & T_m{=}10 \\ \text{else if}(\ \omega > 40\ ) & T_m{=}\text{-}10 \end{array}$$

Click the **Run ▶** button and observe the computer's control of the motor's speed.

- Computers are **slower/faster** than humans in sensing and responding to errors and are **worse/better** at minimizing $\widetilde{\omega}$.
- The plot of motor torque versus time shows that the torque is **seldom/consistently** zero and switches value **infrequently/frequently**.

(d) Click the **Reset** button and then click the box labeled "Use dead band". This instructs Working Model to set $T_m = 0$ when the magnitude of the error in ω is less than 0.5 $\frac{\text{rad}}{\text{sec}}$. Next, click the **Run ▶** button and observe the computer's control of the motor's speed.

- The plot of motor torque versus time shows that the torque is **seldom/consistently** zero and switches value **infrequently/frequently**.

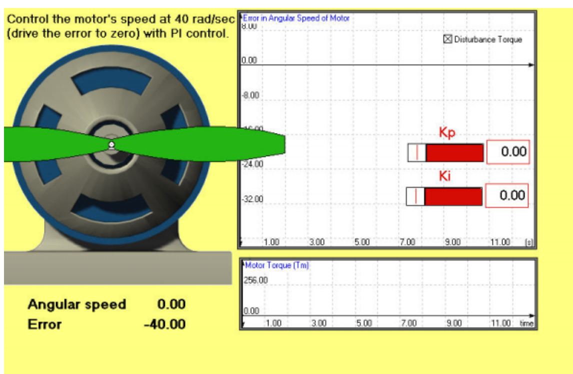
- It seems reasonable that an on/off motor with a dead-band would wear out **slower/quicker** than an on/off motor without a dead-band.
- It seems reasonable that an on/off control with a dead-band would use **less/more** power than an on/off control without a dead-band.
- Explain why house temperature regulated with an on/off control system uses a dead-band.

Lab 10.2 PI (proportional integral) feedback control of motor speed.

One way to control ω is with a ***continuous feedback control*** for T_m that is expressed in terms of the error $\widetilde{\omega}$ between the actual value of ω and ω_{nom}=40 (the desired value of ω) as

$$T_m \;=\; \text{-}k_p * \widetilde{\omega} \;+\; \text{-}k_i * \int_{\bar{t}=0}^{t} \widetilde{\omega}\, d\bar{t} \qquad \text{where} \qquad \widetilde{\omega} \triangleq \omega - \omega_{\text{nom}}$$

To begin this problem, double-click on the file `MotorControlWithKpKi.wm2d`.



To answer each question with Working Model, click the **Reset** button (if necessary) and click and drag the sliders that control the feedback control constants k_p and k_i and try to keep the motor spinning at $\omega = 40\ \frac{\text{rad}}{\text{sec}}$.

To start the simulation, click the **Run** button, and to stop it, click the **Stop** button.

(a) Ensure the "Disturbance Torque" checkbox is **not** checked, set the sliders so $k_p = 2$ and $k_i = 0$, and click the **Run** button. When the error is small, the magnitude of the torque is much **smaller/larger** than the torque for on/off control.

(b) With k_i=0, run four simulations with k_p=1, k_p=2, k_p=3, and k_p=4, respectively. Increasing k_p drives the error to zero **slower/faster**. What physically limits the upper value of k_p?

(c) Click the **Reset** button and then click the box labeled "Disturbance torque". With k_i=0, run four simulations with k_p=1, k_p=2, k_p=3, and k_p=4, respectively. Increasing k_p causes the magnitude of the steady-state error in ω to **decrease/increase**.

(d) Click the **Reset** button and then set k_p=2 (leave the "Disturbance torque" on). Run four simulations with k_i=2, 4, 6, and 8, respectively.
- Increasing k_i results in **less/more** oscillation
- Increasing k_i results in a **smaller/larger** period τ_{period}
- Increasing k_i **decreases/has no effect on/increases** the decay ratio
- Increasing k_i **decreases/has no effect on/increases** the settling time (assume $\zeta > 0$)
- Increasing k_i results in a **smaller/larger** steady-state error