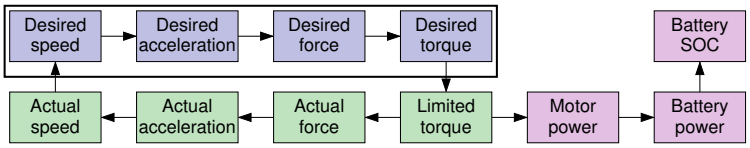
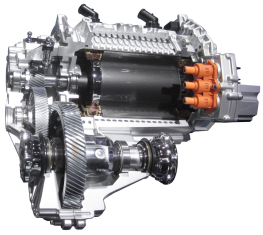
Considering motor and powertrain limits

- You have learned how to compute desired torque vs. time to match a desired speed vs. time profile

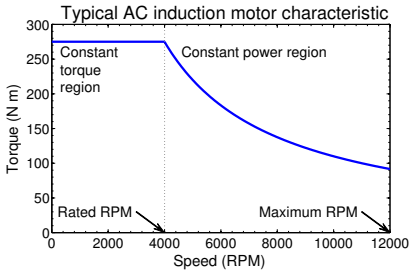




- Now, time to place limits on achieved torque based on motor, powertrain limitations

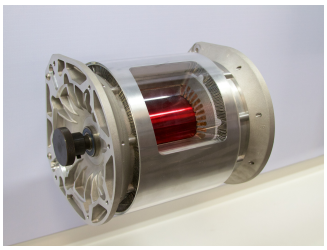
Limiting acceleration torque

- Available torque based on model of ideal three-phase AC induction motor
- When positive torque (acceleration) demanded
  - If prior actual motor speed is less than rated motor speed, then maximum available torque equals rated maximum available torque
  - Otherwise, maximum available torque is computed as (rated maximum available torque [N m]) $\times$ (rated motor speed [RPM]) / (prior actual motor speed [RPM])



Limiting deceleration torque

- When negative torque (deceleration) desired, torque demand split between friction brakes (assume infinitely strong), motor
- Energy recovered from motor replaces energy depleted from battery (less inefficiency losses) via “regeneration”
- Maximum (unsigned) motor torque available for regeneration calculated as minimum of maximum available torque for acceleration and a “regen fraction” times rated maximum available torque
- (Unsigned) limited torque at motor is lesser of demanded motor torque and maximum available torque



Computing actual acceleration

- Now that motor torque limits have been established, can compute actual acceleration force that is available, actual acceleration, and actual velocity
- Compute actual acceleration force $[\text{N}] = [\text{kg m s}^{-2}]$ and actual acceleration $[\text{m s}^{-2}]$

$$\begin{aligned}\text{actual acceleration force} = {} & \text{limited torque at motor [N m]} \times \\ & N\ [\text{u/l}]/\text{wheel radius [m]} - \text{aerodynamic force [N]} - \\ & \text{rolling force [N]} - \text{grade force [N]} - \text{brake drag [N]}\end{aligned}$$

$$\text{actual acceleration} = \text{actual acceleration force [N]}/\text{equivalent mass [kg]}$$

Limit motor speed

- Actual acceleration as just calculated may cause motor to spin at a higher angular velocity than it is rated for
- Therefore, cannot compute actual speed as simply as

$$\text{actual speed}\,[\text{m s}^{-1}] = \text{prior actual speed}\,[\text{m s}^{-1}] + \text{actual acceleration}\,[\text{m s}^{-2}] \times 1\ \text{s}$$

- Instead, we must compute a motor RPM first, then limit that RPM, and then compute the actual vehicle speed

$$\text{test speed}\,[\text{m s}^{-1}] = \text{prior actual speed}\,[\text{m s}^{-1}] + \text{actual acceleration}\,[\text{m s}^{-2}] \times 1\ \text{s}$$

$$\text{motor speed [RPM]} = \text{test speed}\,[\text{m s}^{-1}] \times N\ [\text{u/l}] \times \frac{60\ [\text{s min}^{-1}]}{2\pi\ [\text{rev}^{-1}] \times \text{wheel radius [m]}}$$

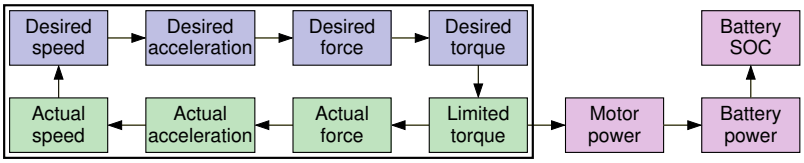
- Limit motor speed by max. rated motor speed to make limited motor speed [RPM]

Compute actual vehicle speed

- Finally, now that we have calculated limited motor speed, actual vehicle speed is computed as

$$\begin{aligned}\text{actual speed}\,[\text{m s}^{-1}] = {} & \text{limited motor speed [RPM]} \times 2\pi\ [\text{rev}^{-1}] \times \\ & \text{wheel radius [m]}/(60\ [\text{s min}^{-1}] \times N\ [\text{u/l}])\end{aligned}$$

- The full circuit from desired to actual speed has now been described



Summary

- You now know how to put limits on desired torque to produce actual speed
  - Apply torque limits due to motor design
  - Apply speed limits due to motor design
  - Compute actual acceleration
  - Compute actual speed
- Now ready to compute impact of power demand on battery

Credits

Credits for photos in this lesson

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