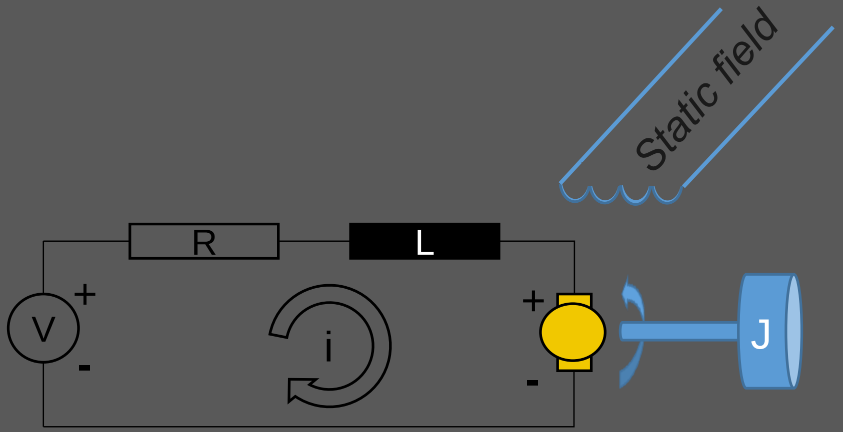
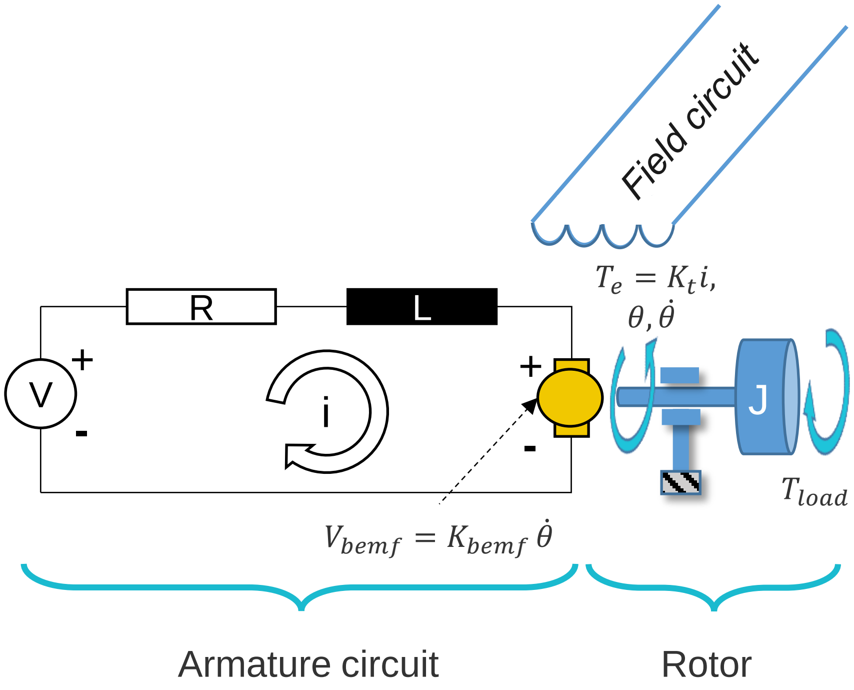
Modeling and Simulation of a simplified DC-motor using solidThinking Activate



Simplified DC-motor

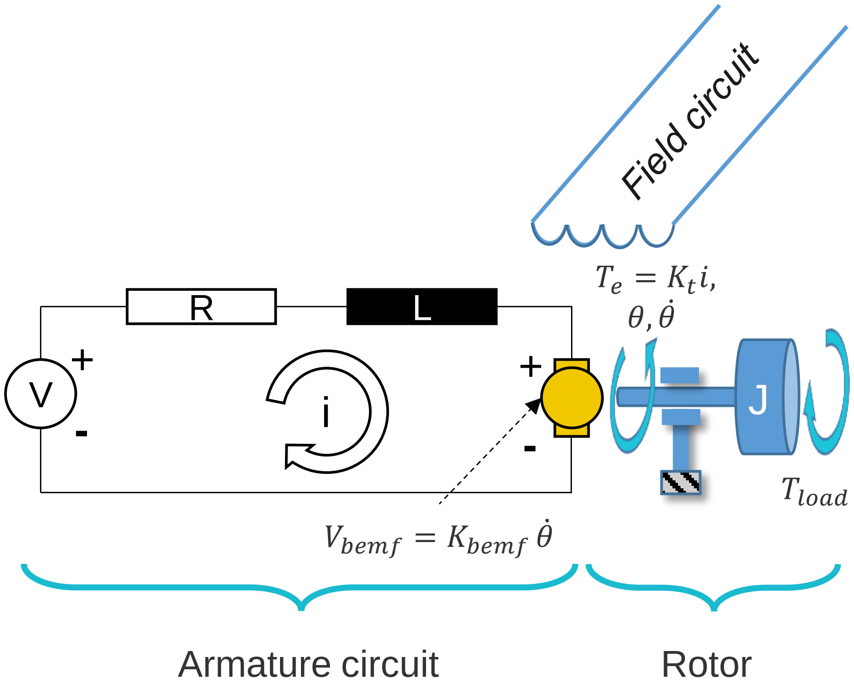
The DC motor rotor speed is controlled by application of a DC voltage V to its armature winding. The armature winding is modeled as a series resistor-inductor, RL, circuit. The applied DC voltage produces an armature current. The motor torque constant, K_t, which depends on the number of armature windings, converts the armature current to an electromagnetic torque, T_e. When the motor is driving a load the, the difference between the electromagnetic torque and the load torque, T_{load}, produces an applied torque which produces rotor speed, $\dot{\theta}$. As the rotor speed increases a *back-emf* voltage, V_{bemf}, is produced, which limits the armature current and rotor speed both. The back-emf voltage is related to the rotor speed by the back-emf constant, K_{bemf}.



Simplified DC-motor

Objectives

- Learn how to…
  - … translate electrical systems into *Activate* block diagrams
  - … validate or change motor parameters via time constants



Creation and Simulation of a simplified DC motor

Theoretical background and how to implement it using *Activate*

Step 1: Construction of equations

- Step 1.1: Motor torque and back emf constant
- Step 1.2: Electrical circuit
- Step 1.3: Mechanical circuit

Step 2: Implementation using *Activate*

Step 3: Electrical and mechanical time constants

Step 4: Validation of the results

Step 1: Construction of equations

- Step 1.1: Motor torque constant and back emf constant

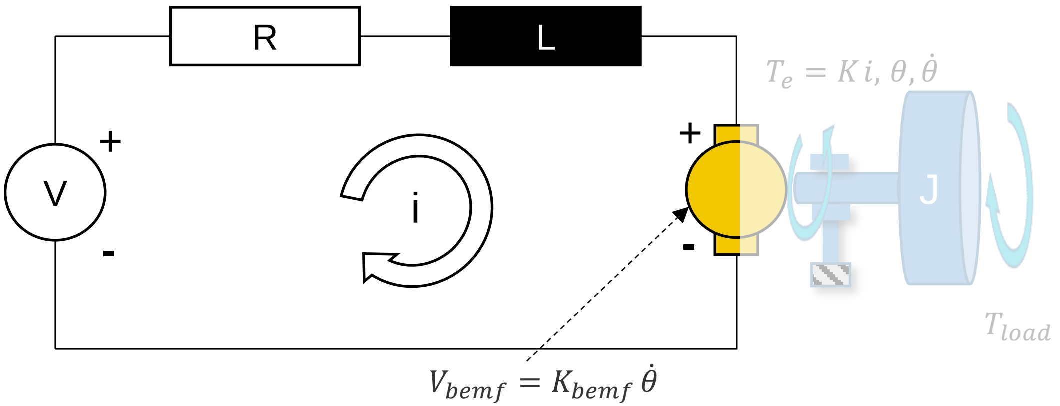
- Equations:
- Mechanical part: $T = K_t i$
- Electrical part: $\mathrm{V_{bemf}} = K_{bemf}\dot{\theta}$

- In SI-units: $K_{bemf} = \frac{Vs}{rad} \overset{?}{=} \frac{Nm}{A} = K_t$
  - $\frac{Vs}{rad} = \frac{(kgm^2 s^{-3} A^{-1})s}{1\left(\frac{m}{m}\right)} = \frac{kgm^2}{s^2 A} = \frac{Nm}{A}$
  - $K_{bemf} \overset{!}{=} K_t := K$

Step 1: Construction of equations

- Step 1.2: Electrical circuit

- Equations:
- *Kirchhoff's circuit laws*
  - $V = V_r + V_L + V_{bemf}$
  - $V = Ri + L\frac{\partial i}{\partial t} + K\dot{\theta}$
  - $\frac{\partial i}{\partial t} = \frac{1}{L}(V - Ri - K\dot{\theta})$



Step 1: Construction of equations

- Step 1.3: Mechanical circuit

- Equations:
- $J\ddot{\theta} = T_e - T_B - T_{load}$
- $J\ddot{\theta} = Ki - B\dot{\theta} - T_{load}$

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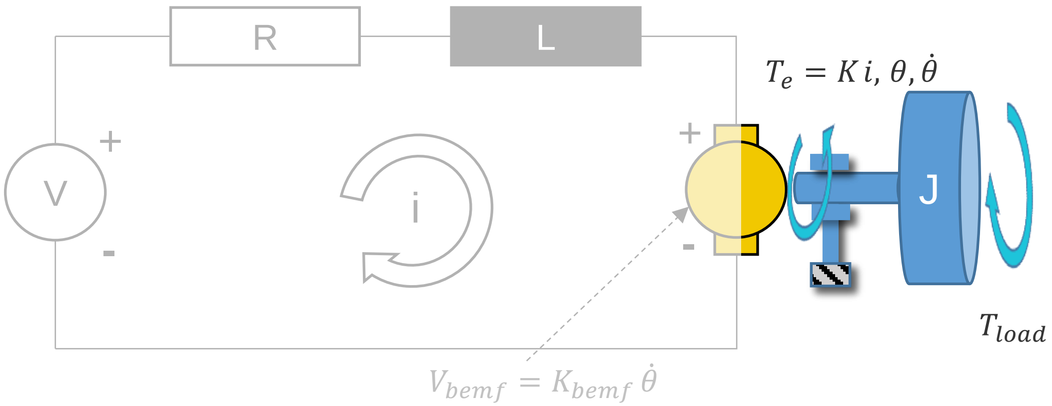
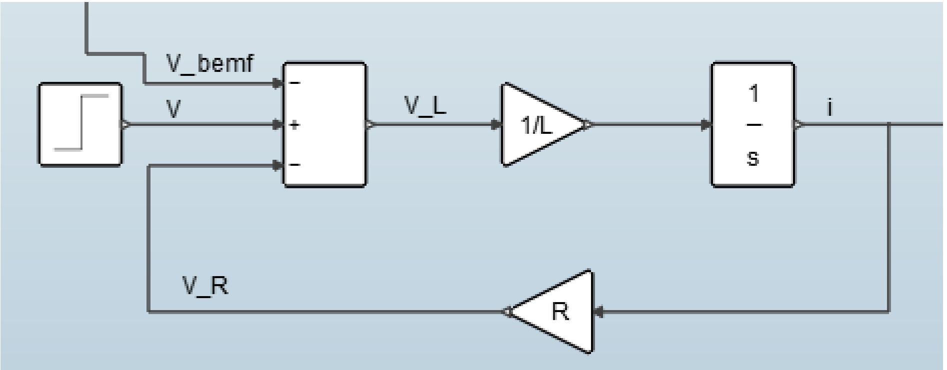


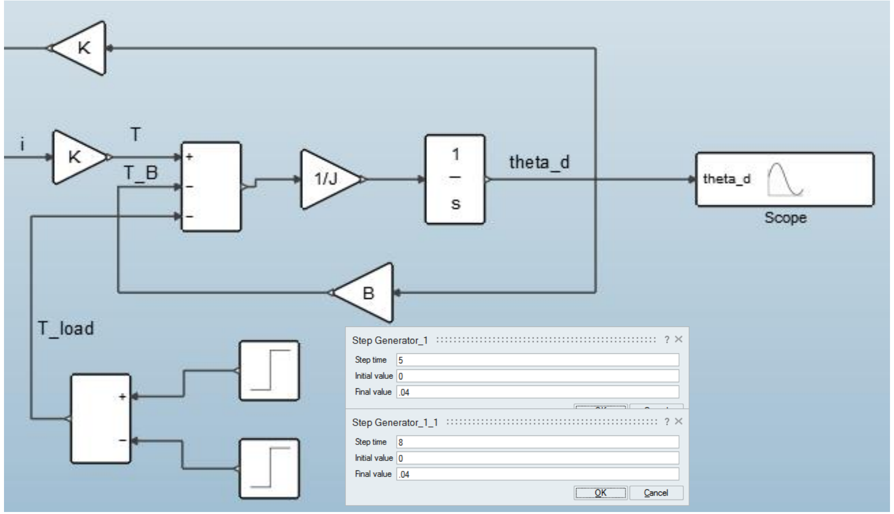
Step 2: Implementation using *Activate*

- The electric circuit behaves like its mechanical counterpart.
- And follows the equation:
  - $\frac{\partial i}{\partial t} = \frac{1}{L}(V - Ri - K\dot{\theta})$



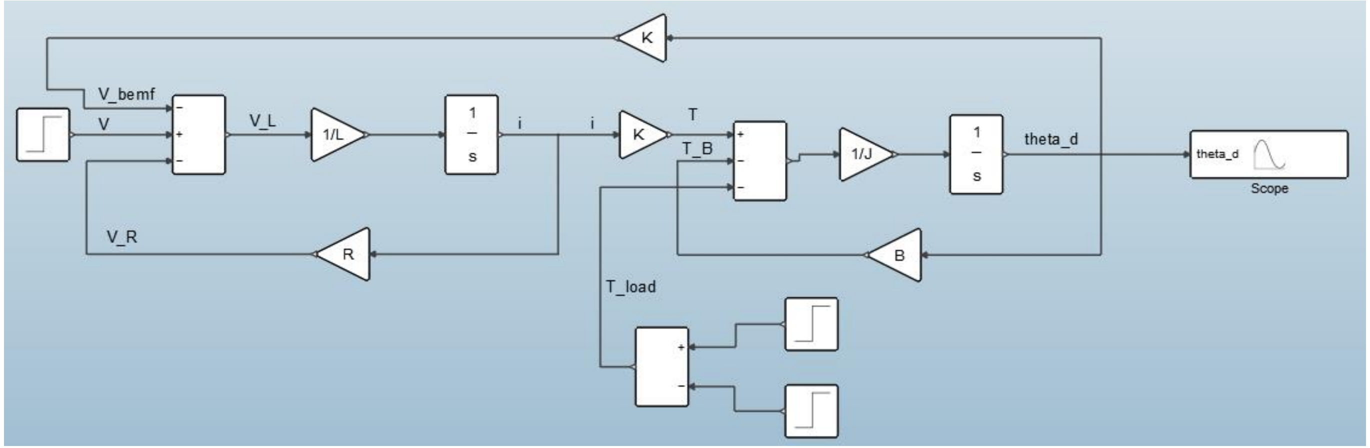
Step 2: Implementation using *Activate*

- The motor torque constant, K, which depends on the number of armature windings, converts the armature current to an electromagnetic torque:
  - $T = Ki$
- $J\ddot{\theta} = Ki - B\dot{\theta} - T_{load}$



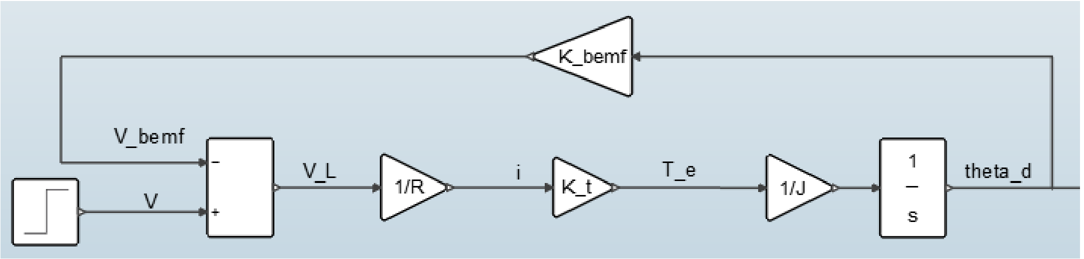
Step 2: Implementation using *Activate*

- *Completed model:*
- As the rotor speed increases a back-emf voltage, V_{bemf}, is produced, which limits the armature current and rotor speed both.



Step 3: Electrical and mechanical time constants

- The Electrical Time Constant is the time constant associated with the armature dynamics and is calculated as $\tau_e = \frac{L}{R}$.
- The Mechanical Time Constant is the time constant associated with the mechanical dynamics of the motor and is calculated by setting
  - the load torque to zero ($T_{load} = 0$),
  - replacing the electrical dynamics with their DC-value ($\left.\frac{1}{Ls+R}\right|_{s\to 0} = \frac{1}{R}$),
  - the motor friction to zero ($B = 0$).
- Applying these setting results in the following block diagram:



Step 3: Electrical and mechanical time constants

- The closed loop transfer function of the simplified motor model is calculated as:
  - $\frac{\omega}{V} = \frac{K_t}{RJs+K_tK_{bemf}}$
- And the Mechanical Time Constant is calculated as:
  - $\tau_m = \frac{RJ}{K_tK_{bemf}}$
- In successful applications, the Mechanical Time Constant should be the fundamental (or dominant) time constant, typically 100 to 1000 times slower than the electrical time constant.

Step 4: Validation of the results

- With the given parameters (Fig. 3) the rotor increases speed without a load torque to a limit of $1.2\frac{rad}{s}$.
- Applying a load torque of $0.4Nm$ reduces the rotor speed to $0.8\frac{rad}{s}$.
- Calculate the time constants of the motor
  - In this example: $\tau_e = 0.0001\ sec.;\ \tau_m = 0.2\ sec.$
  - $\frac{\tau_m}{\tau_e} = 2000$ ☑

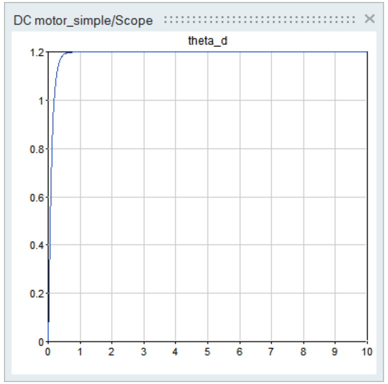


Fig. 1: Rotor speed without load torque

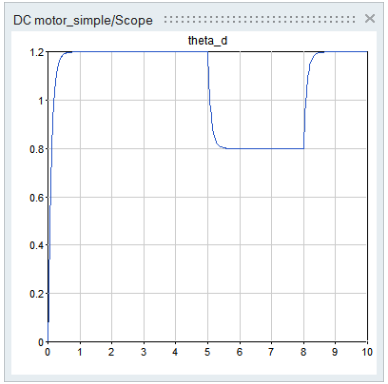


Fig. 2: Rotor speed with applied load torque

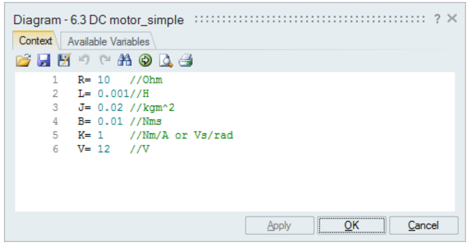


Fig. 3: Initialized values of parameters