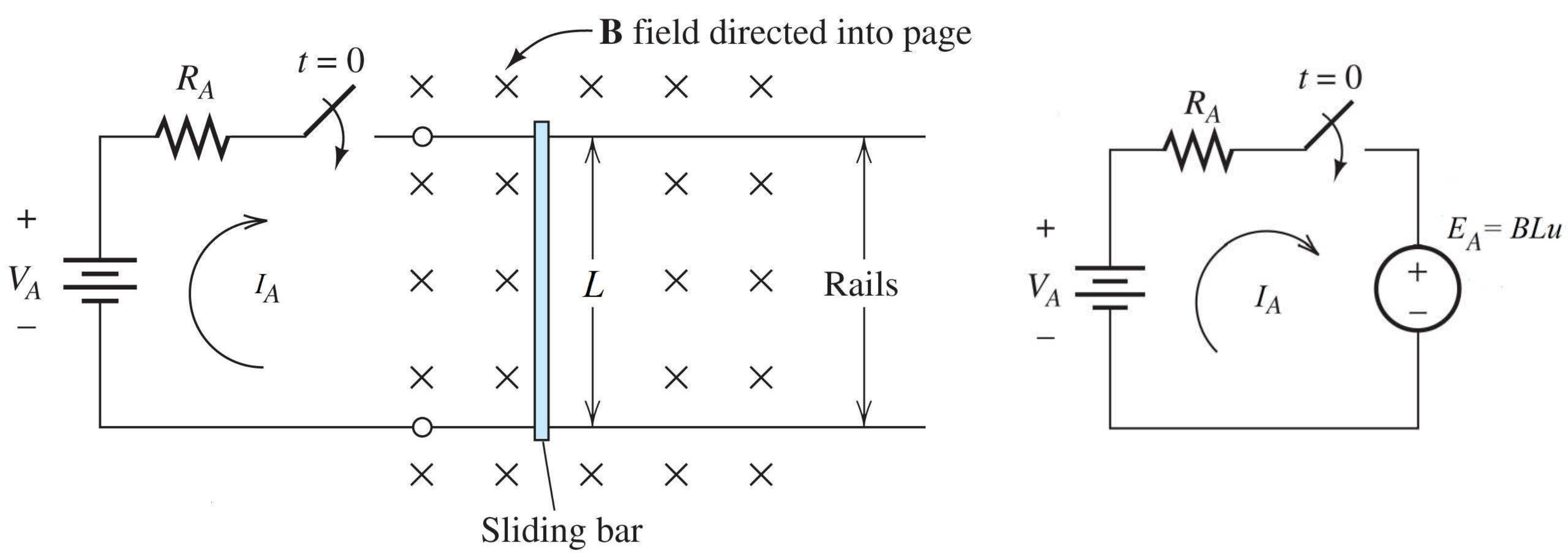
Lesson 14: Permanent magnet DC machine speed control

Linear motor summary

$F = I_A LB$ force exerted on bar due to current I_A

$E_A = BLu$ induced voltage due to velocity of bar u

$I_A = \frac{V_A - E_A}{R_A}$ current in the bar



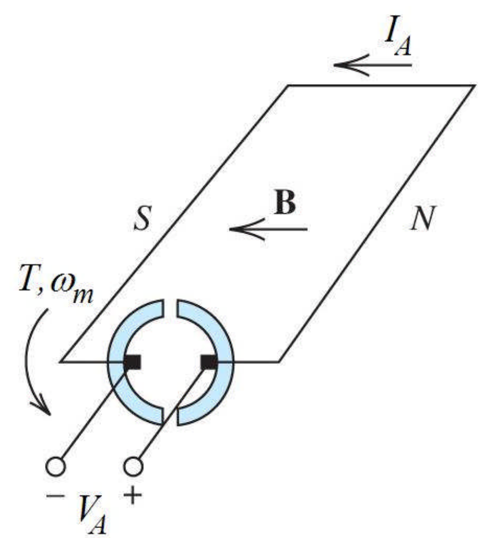
Rotating dc motor summary

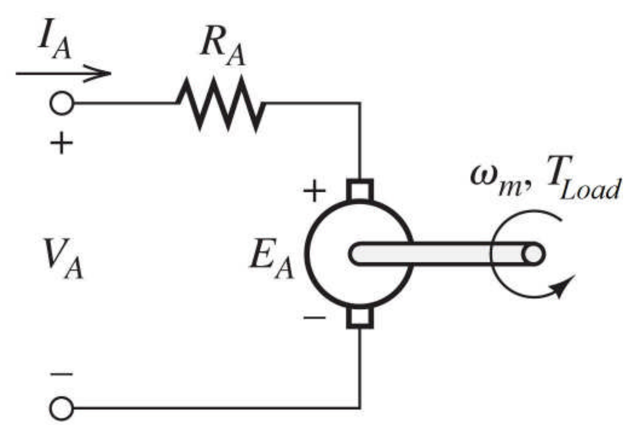
$$T_e = K_v I_A$$ torque developed due to current I_A

$$E_A = K_v \omega_m$$ back emf due to rotational velocity ω_m

$$I_A = \frac{V_T - E_A}{R_A}$$ armature current

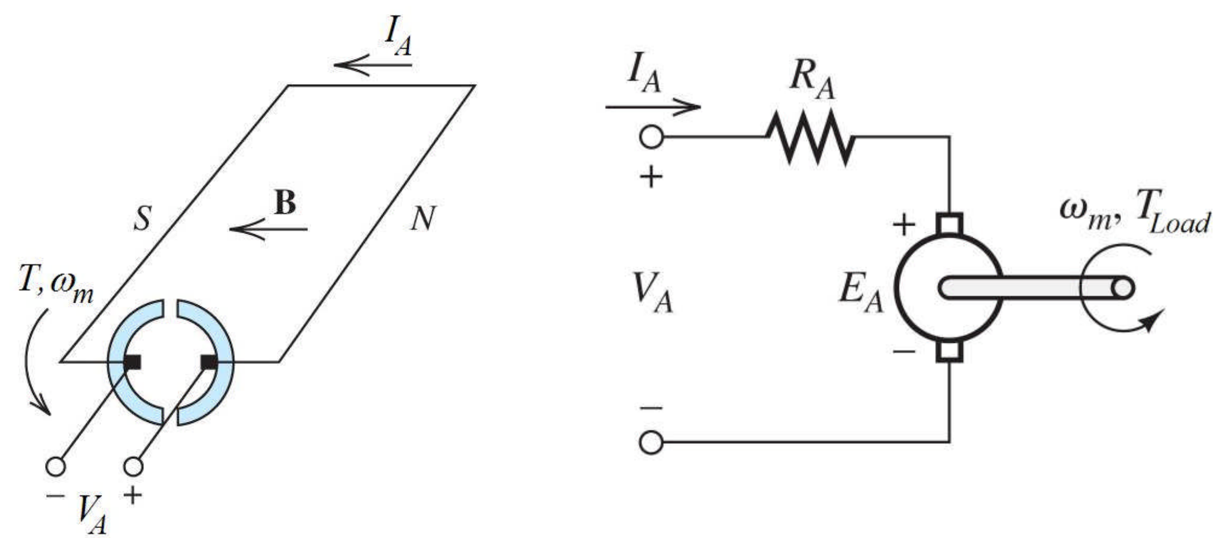
$$T_{Load} = T_e - T_{Loss}$$ output torque





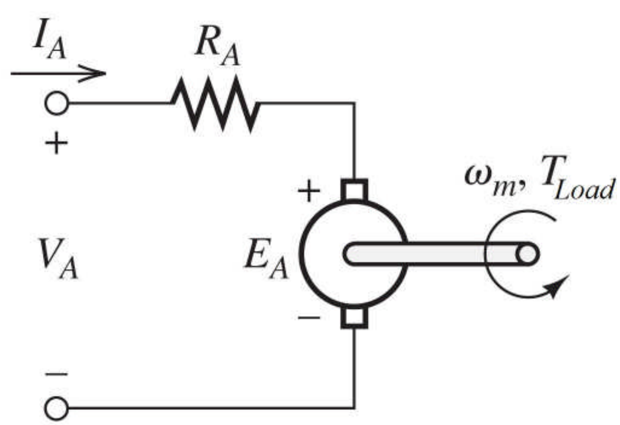
Speed control

- What determines the motor speed ω_m?
- How can we *control* the motor speed ω_m?



Torque-speed characteristic

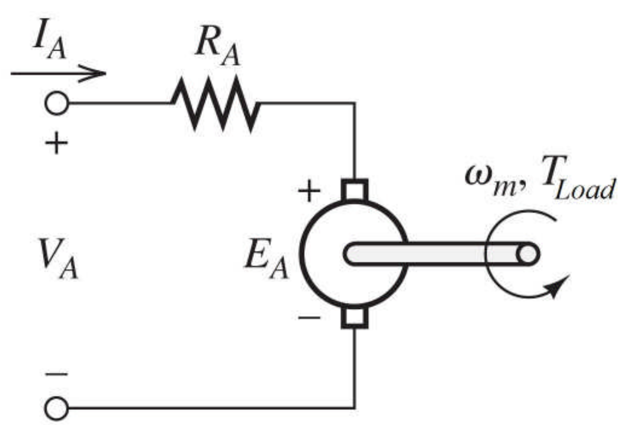
- Steady-state motor speed ω_m is determine by the balance between T_{Load} and T_e . (assuming $T_{Loss} = 0$).
- Write and expression for T_e in terms of V_A.



Torque-speed characteristic

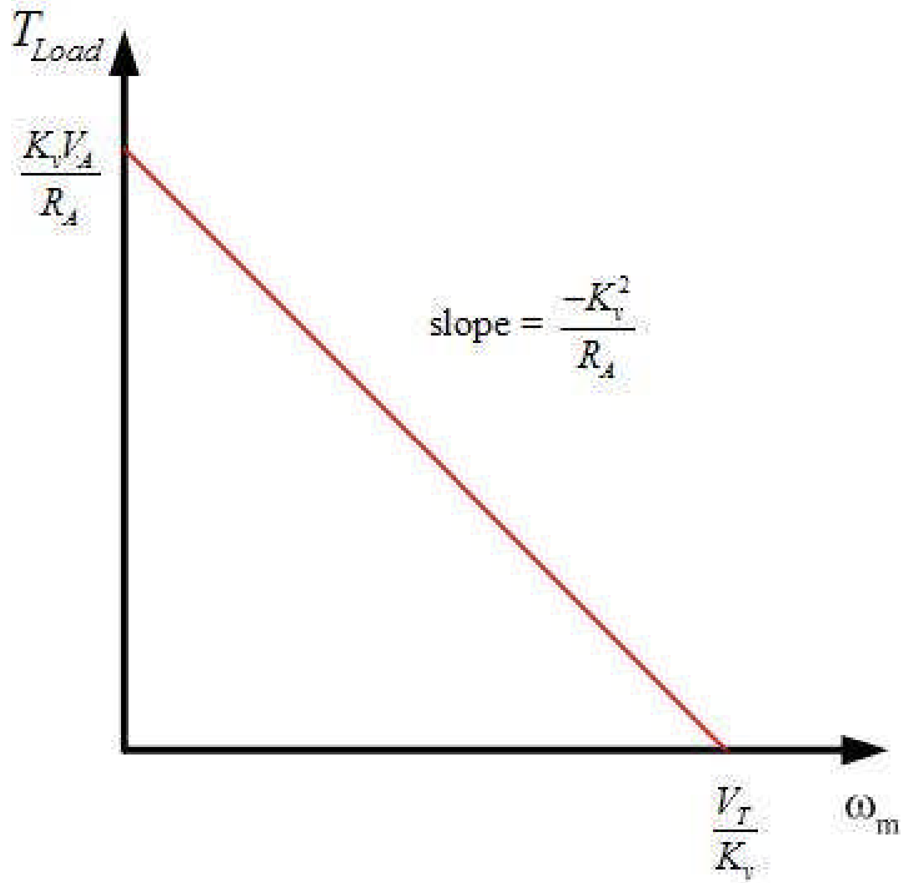
- Write and expression for T_e in terms of V_A.

$$
\begin{aligned}
T_e &= K_v I_A \\
&= K_v \left(\frac{V_T - E_A}{R_A} \right) \\
&= \frac{K_v V_A}{R_A} - \frac{K_v^2}{R_A} \omega_m
\end{aligned}
$$



Motor torque-speed characteristic

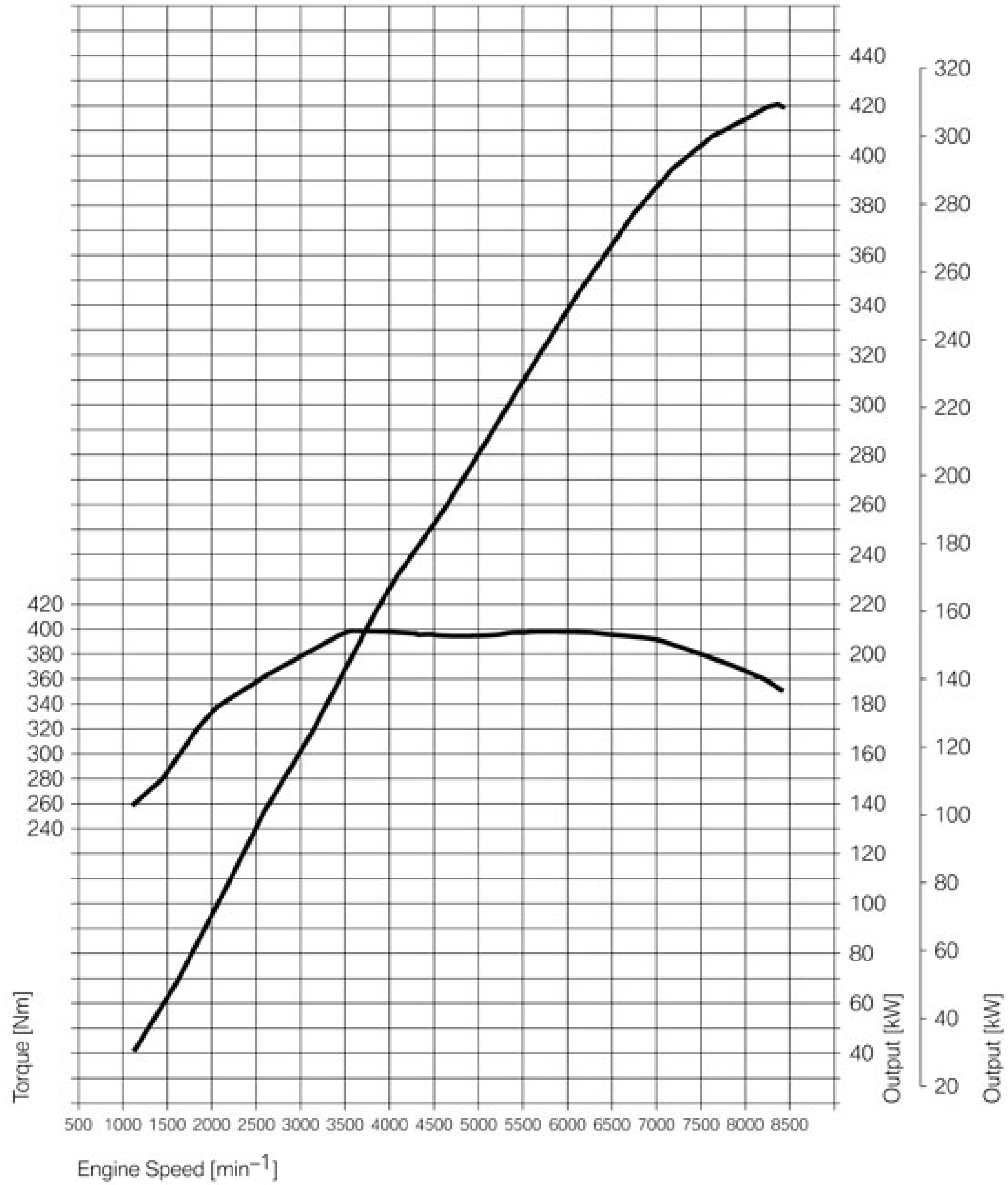
$$T_e = \frac{K_v V_A}{R_A} - \frac{K_v^2}{R_A}\omega_m$$



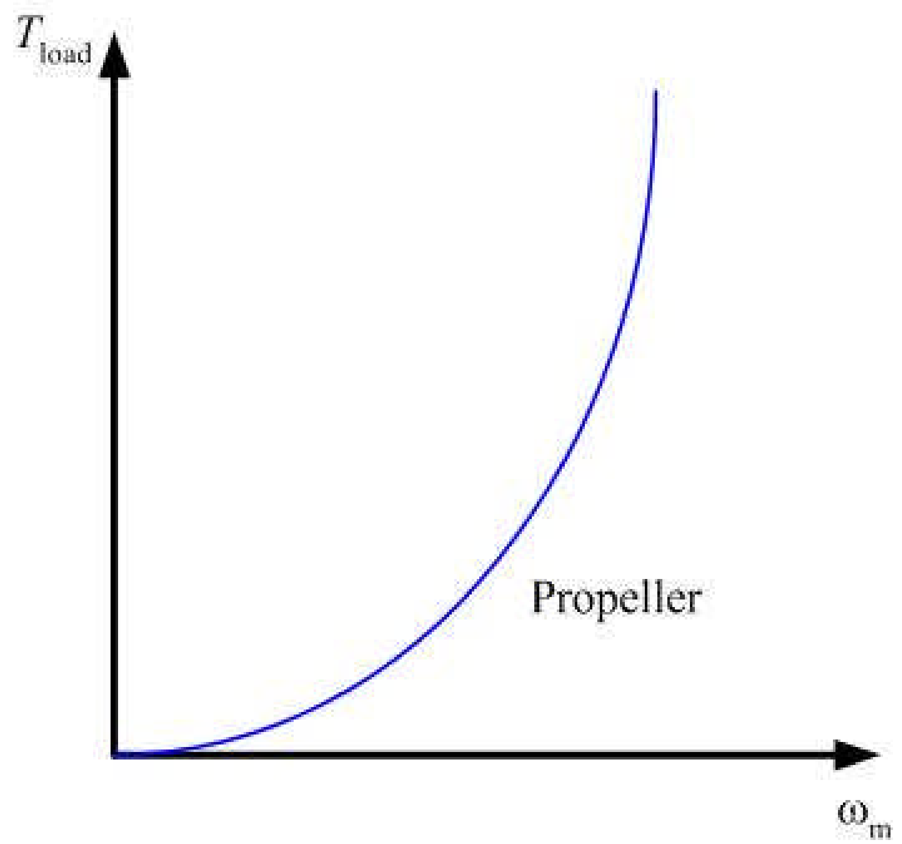
BMW M3 V-8

[The New M3]

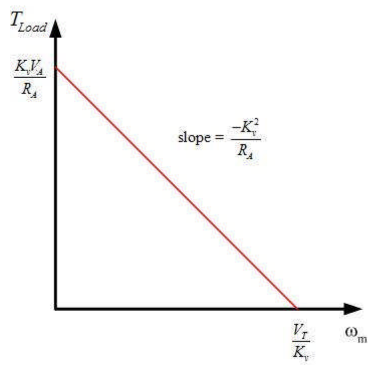
BMW M3 V8 torque-speed characteristic

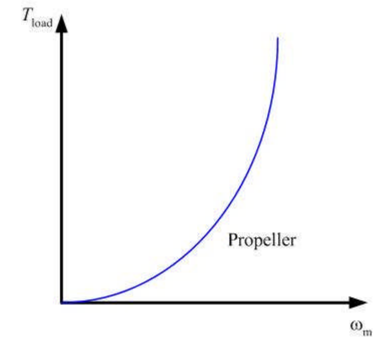


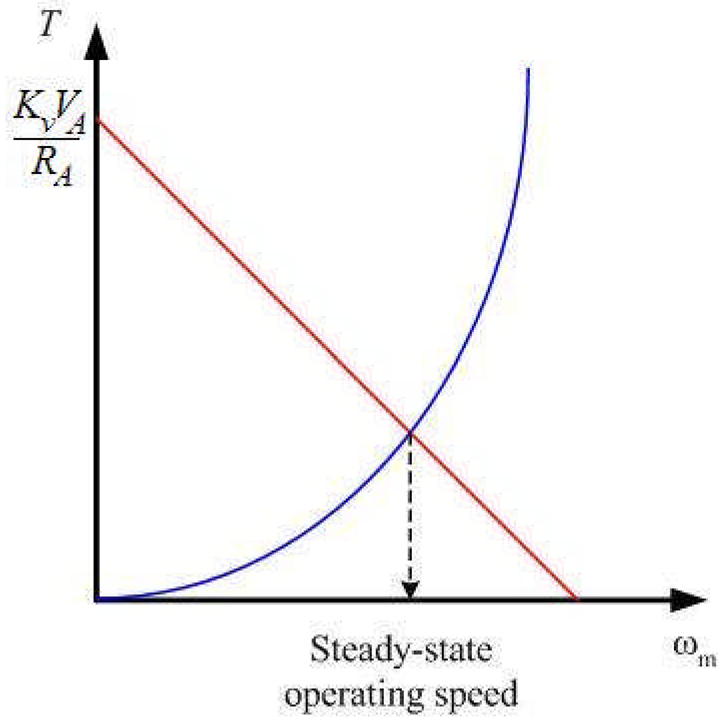
Load torque-speed characteristic



Overlay torque-speed characteristics



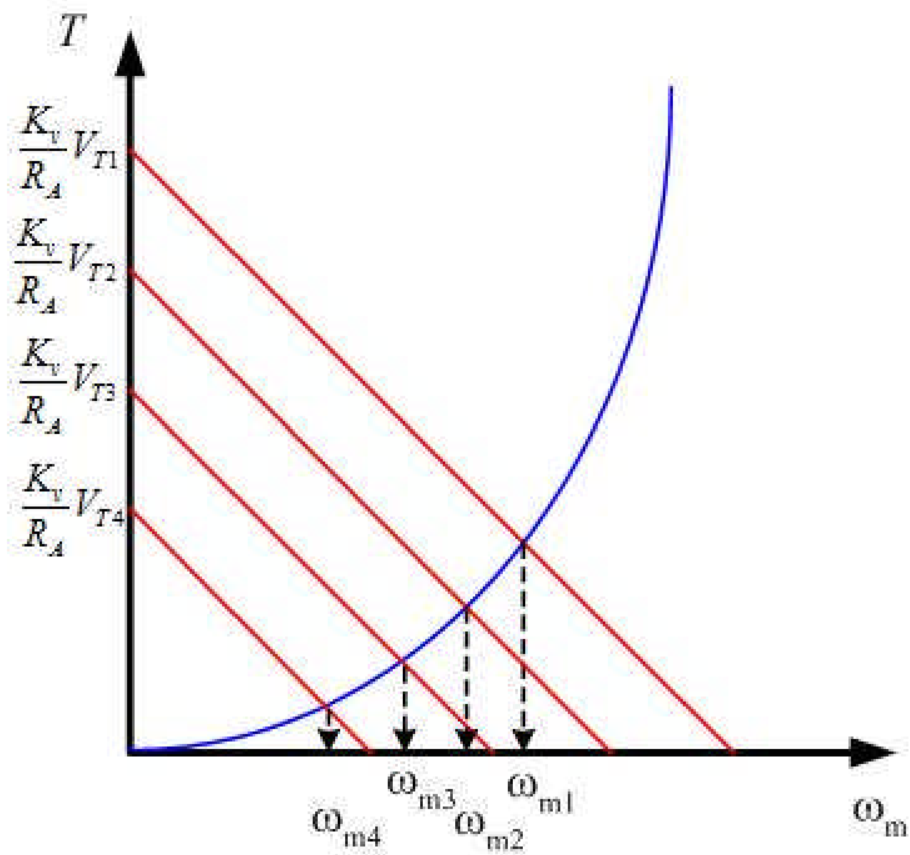




Controlling steady-state speed

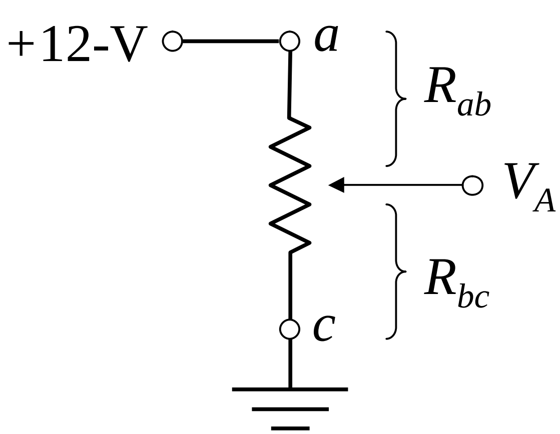
- If the load characteristic is fixed, we can adjust the steady-state speed by varying the source voltage V_A.
- Adjusting V_A shifts the motor's torque-speed characteristic vertically yields a new operating point and thus a new steady-state speed.

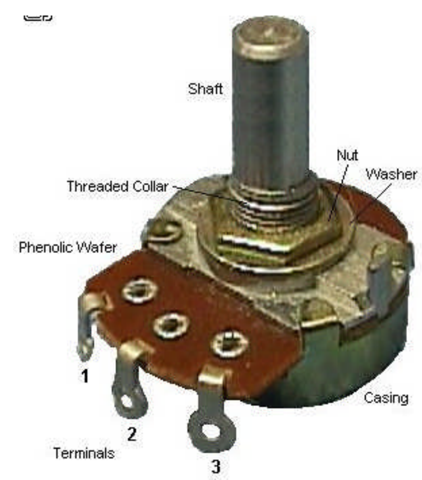
Controlling steady-state speed



Method of adjusting source voltage

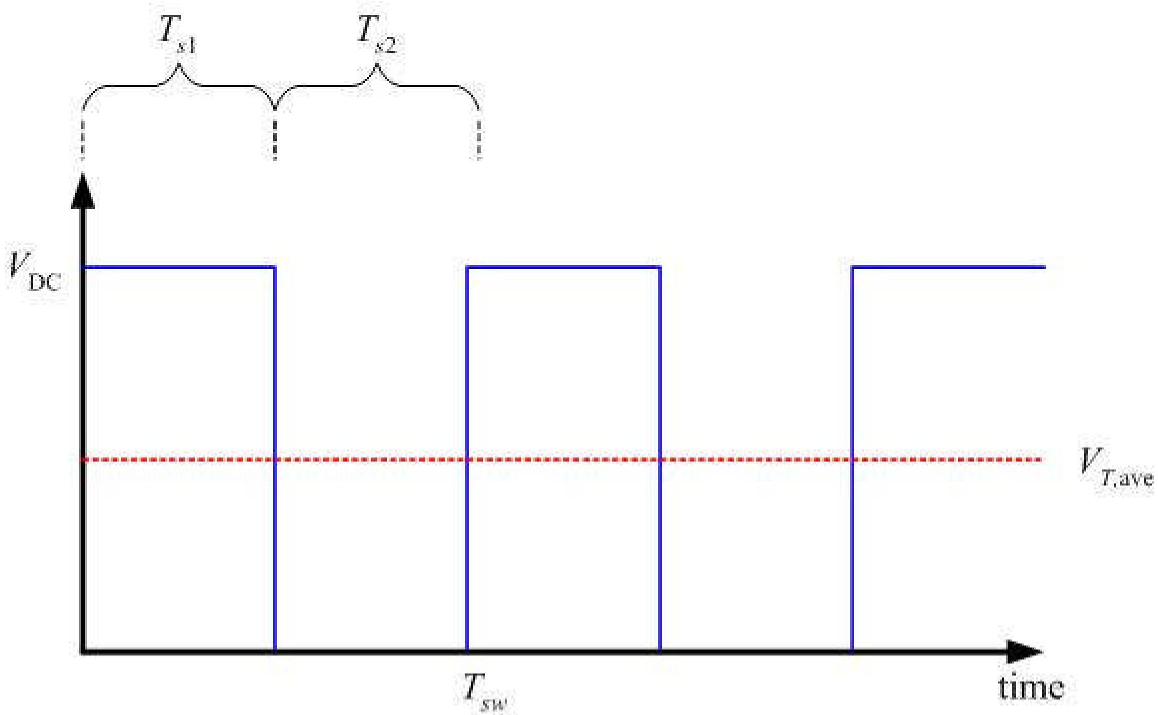
- A simple method of adjusting voltage would be to use a variable resistor.
- This is inefficient and impractical for other than small motors.





Method of adjusting source voltage

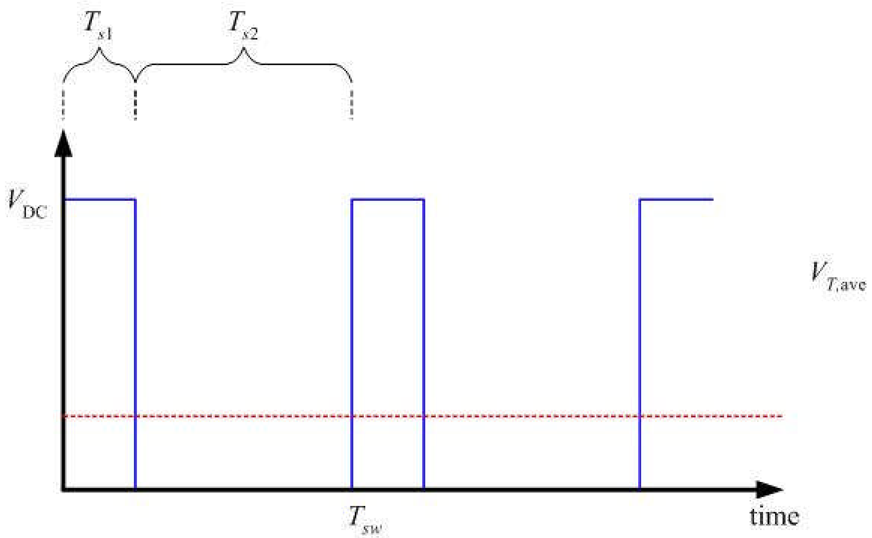
- A more efficient method uses a square wave with an adjustable duty cycle (*D*).



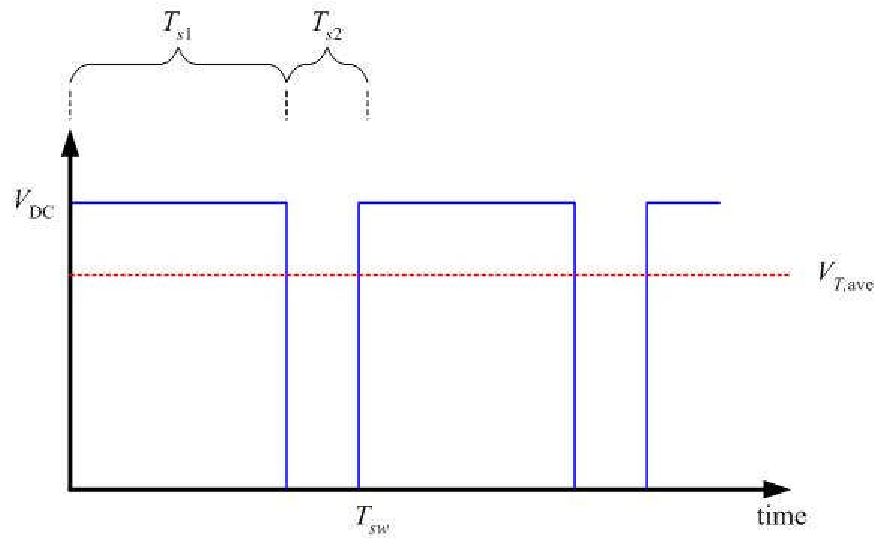
$$D = \frac{T_{s1}}{T_{sw}}$$

$$V_{A,ave} = \frac{T_{s1} V_{DC}}{T_{sw}} = D V_{DC}$$

Adjusting duty cycle



$D = 25\%$



$D = 75\%$

Example Problem 1

A permanent magnet DC motor is rated for 24V, 2A and 1500 rpm. If the machine is 85% efficient at rated condition, find R_A and K_v. If T_{Load} = 0.18 N·m, what is the new mechanical speed?

Example Problem 2

Suppose we wish to change the speed of the machine in the previous example to operate at 100 rad/s with T_{load} = 0.18 N·m applied, what is the required average armature voltage $V_{A,\mathrm{ave}}$? If the DC voltage is 24 V, what is the required duty cycle?