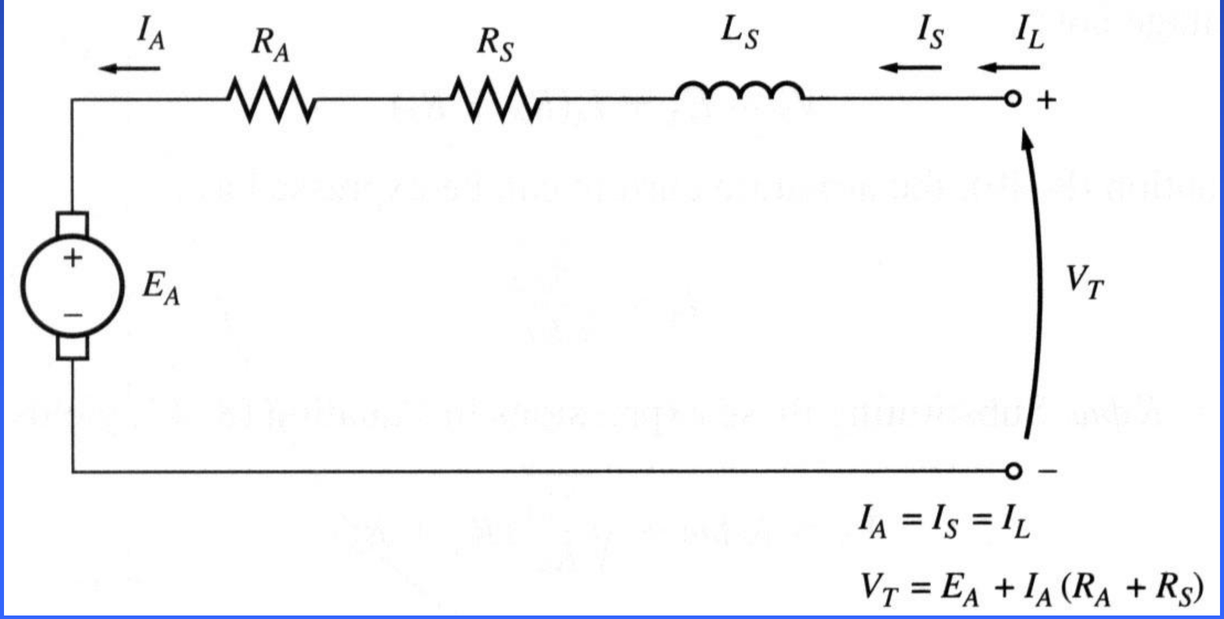
Motor types: The series DC motor

A series DC motor is a DC motor whose field windings consists of a relatively few turns connected in series with armature circuit. Therefore:

$$V_T = E_A + I_A(R_A + R_s) \quad (5.75.1)$$



Series motor: induced torque

The terminal characteristic of a series DC motor is quite different from that of the shunt motor since the flux is directly proportional to the armature current (assuming no saturation). An increase in motor flux causes a decrease in its speed; therefore, a series motor has a dropping torque-speed characteristic.

The induced torque in a series machine is

$$\tau_{ind} = K\phi I_A \qquad (5.76.1)$$

Since the flux is proportional to the armature current:

$$\phi = cI_A \qquad (5.76.2)$$

where c is a proportionality constant. Therefore, the torque is

$$\tau_{ind} = KcI_A^2 \qquad (5.76.3)$$

Torque in the motor is proportional to the square of its armature current. Series motors supply the highest torque among the DC motors. Therefore, they are used as car starter motors, elevator motors etc.

Series motor: terminal characteristic

Assuming first that the magnetization curve is linear and no saturation occurs, flux is proportional to the armature current:

$$\phi = cI_A \tag{5.77.1}$$

Since the armature current is

$$I_A = \sqrt{\frac{\tau_{ind}}{Kc}} \tag{5.77.2}$$

and the armature voltage

$$E_A = K\phi\omega \tag{5.77.3}$$

The Kirchhoff's voltage law would be

$$V_T = E_A + I_A(R_A + R_S) = K\phi\omega + \sqrt{\frac{\tau_{ind}}{Kc}}\left(R_A + R_S\right) \tag{5.77.4}$$

Since (5.77.1), the torque:

$$\tau_{ind} = KcI_A^2 = \frac{K}{c}\phi^2 \tag{5.77.5}$$

Series motor: terminal characteristic

Therefore, the flux in the motor is

$$\phi = \sqrt{\frac{c}{K}}\sqrt{\tau_{ind}} \qquad (5.78.1)$$

The voltage equation (5.77.4) then becomes

$$V_T = K\sqrt{\frac{c}{K}}\sqrt{\tau_{ind}}\,\omega + \sqrt{\frac{\tau_{ind}}{Kc}}\left(R_A + R_S\right) \qquad (5.78.2)$$

which can be solved for the speed:

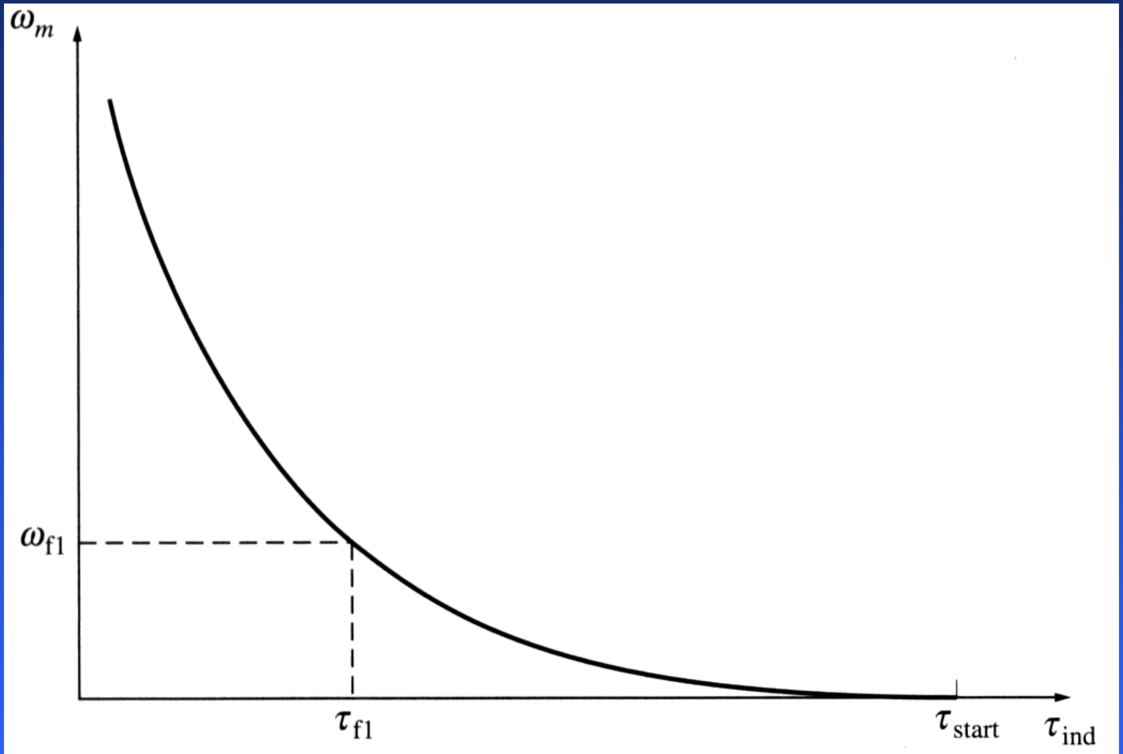
$$\omega = \frac{V_T}{\sqrt{Kc}}\frac{1}{\sqrt{\tau_{ind}}} - \frac{R_A + R_S}{Kc} \qquad (5.78.3)$$

The speed of unsaturated series motor inversely proportional to the square root of its torque.

Series motor: terminal characteristic

One serious disadvantage of a series motor is that its speed goes to infinity for a zero torque.

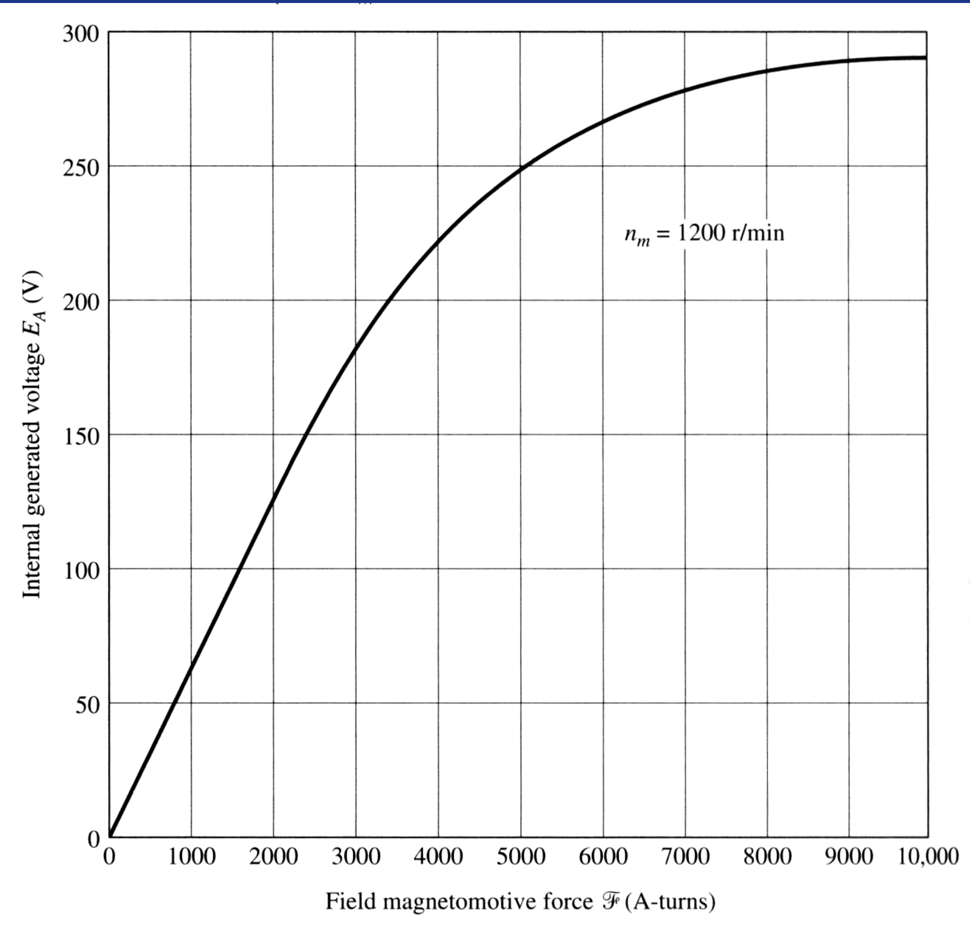
In practice, however, torque never goes to zero because of the mechanical, core, and stray losses. Still, if no other loads are attached, the motor will be running fast enough to cause damage.



Steps must be taken to ensure that a series motor **always** has a load! Therefore, it is not a good idea to connect such motors to loads by a belt or other mechanism that could break.

Series motor: terminal characteristic – Example

Example 5.4: A 250 V series DC motor with compensating windings has a total series resistance $R_A + R_S$ of 0.08 Ω. The series field consists of 25 turns per pole and the magnetization curve is



a) Find the speed and induced torque of this motor when its armature current is 50 A.
b) Calculate and plot its torque-speed characteristic.

a) To analyze the behavior of a series motor with saturation, we pick points along the operating curve and find the torque and speed for each point. Since the magnetization curve is given in units of mmf (ampere-turns) vs. E_A for a speed of 1200 rpm, calculated values of E_A must be compared to equivalent values at 1200 rpm.

Series motor: terminal characteristic – Example

For $I_A = 50$ A

$$E_A = V_T - I_A(R_A + R_S) = 250 - 50 \cdot 0.08 = 246\,V$$

Since for a series motor $I_A = I_F = 50$ A, the mmf is

$$\mathcal{F} = NI = 25 \cdot 50 = 1250 \;\; A - turns$$

From the magnetization curve, at this mmf, the internal generated voltage is $E_{A0} = 80$ V. Since the motor has compensating windings, the correct speed of the motor will be

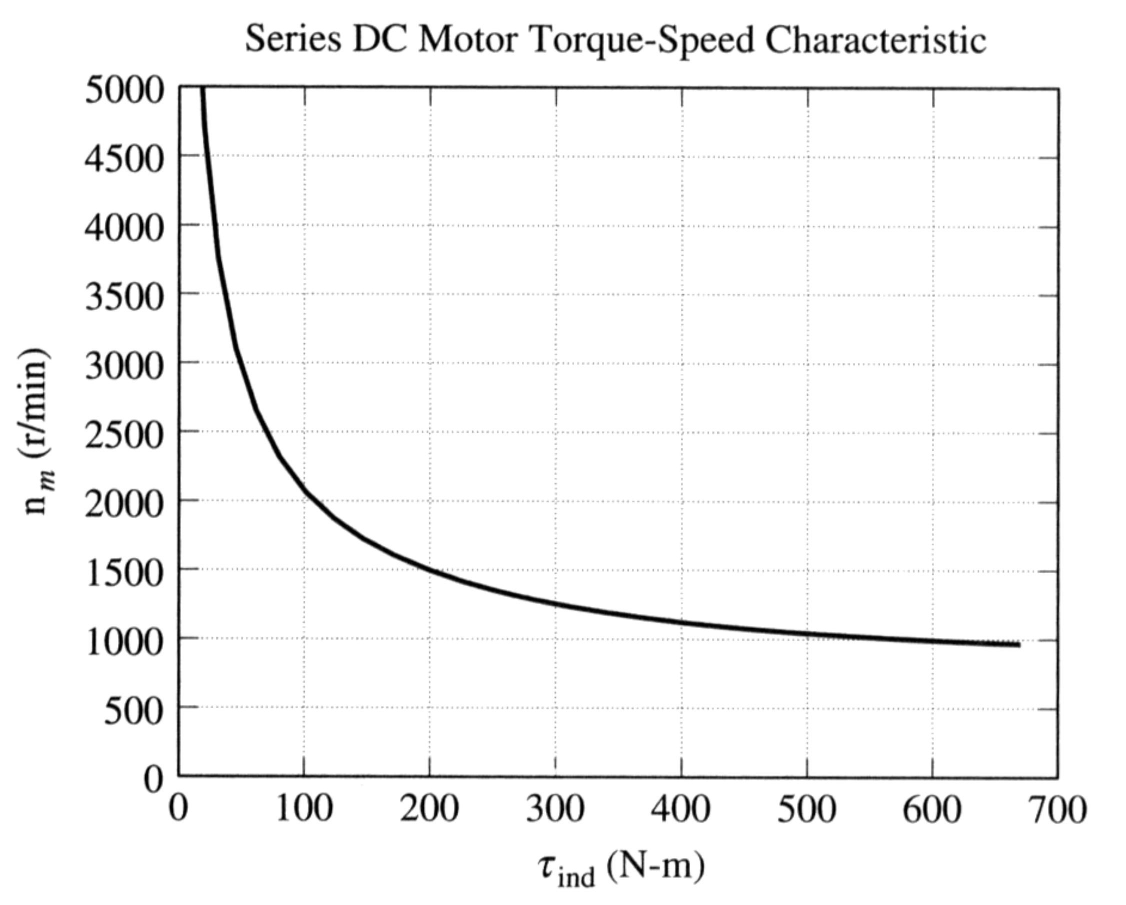
$$n = \frac{E_A}{E_{A0}} n_0 = \frac{246}{80} 1200 = 3690 \;\; rpm$$

The resulting torque: $$\tau_{ind} = \frac{E_A I_A}{\omega} = \frac{246 \cdot 50}{3690 \cdot 2\pi/60} = 31.8 \;\; N\text{-}m$$

Series motor: terminal characteristic – Example

b) The complete torque-speed characteristic

We notice severe over-speeding at low torque values.



Series motor: Speed control

The only way to control speed of a series DC motor is by changing its terminal voltage, since the motor speed is directly proportional to its terminal voltage ***for any given torque***.