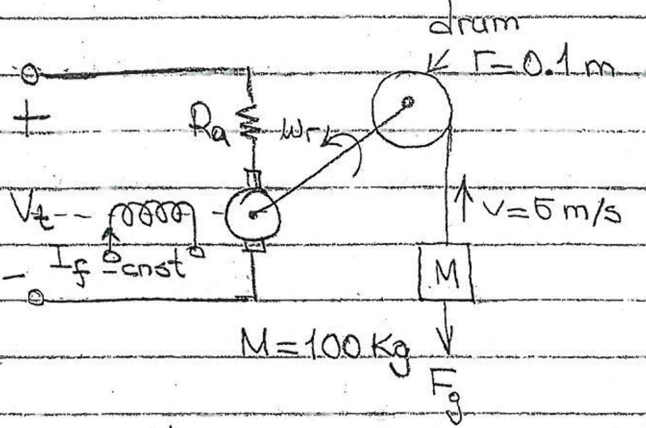
Example 1. Crane Hoist



A separately excited dc motor is operating in a crane-hoist. Its field excitation is kept constant. $R_a = 0.5\ \Omega$ and $I_a = 100$ A are given.

Find the applied armature voltage V_t in order to rise (ascend) the load at a constant speed of $v = 5$ m/s (Hoisting problem).

Since hoisting speed is constant, accelerating torque is zero ($J\frac{d\omega_r}{dt} = 0$) in torque-balance equation ($J\frac{d\omega_r}{dt} = T_e - (T_L + T_{f\&w})$), which implies that

$T_e = (T_L + T_{f\&w})$ during constant speed operation in the steady state. Neglect also friction and windage torque $\Longrightarrow$ $T_e = T_L$

Electromechanical Torque — Load Torque

Load torque, $T_L = F_g \cdot r$

Torque arm (radius of drum or pulley)

Gravitational force acting on the load, $F_g = Mg$

$\therefore T_L = Mgr = 100 \times 10 \times 0.1 = 100$ Nm //

This system converts linear motion to rotational motion

$\therefore \omega_r = \left(\frac{\text{linear speed}}{\text{circumference of the drum}}\right) \times 2\pi$

$\omega_r = \frac{v}{2\pi r} \cdot 2\pi = v/r$ //

$\omega_r = \frac{5.0}{0.1} = 50$ rad/s $\equiv 50$ rad/s $\times \frac{60\ \text{sec/min}}{2\pi\ \text{rad/revolution}} = 477.5$ rpm //

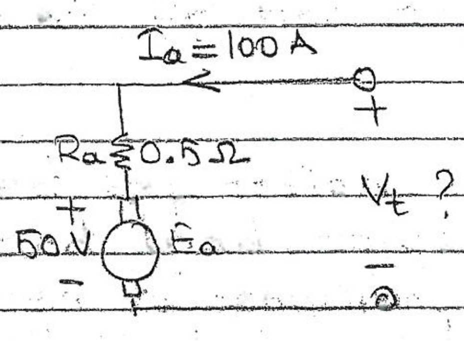
$T_e = K_a \Phi_d I_a = T_L = 100\ Nm$

$100 = K_a \Phi_d \times 100 \Rightarrow K_a \Phi_d = 1.0$ //

Therefore, $E_a = K_a \Phi_d \omega_r = 1.0 \times 50 = 50$ Volts //

For Motoring mode

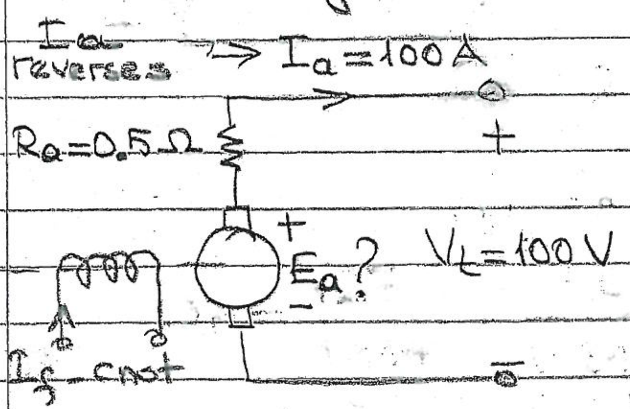
$V_t = E_a + R_a I_a$
$= 50 + 0.5 \times 100$



$\therefore V_t = 100$ V //

Now the dc m/c lowers (descends) the load at constant speed. Constant speed lowering is called "overhauling". Find the speed at which the dc m/c can overhaul the load by assuming that V_t remains the same

Since $T_L = T_e = 100$ Nm is the same $I_a = 100$ does not change.



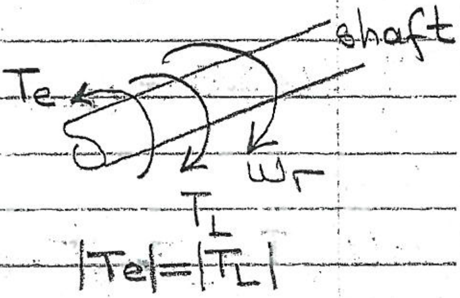
Electromechanical torque, T_e should oppose load torque T_L and direction of rotation in order to produce "braking effect" on the mass, M which moves down under the influence of F_g.

Therefore, the operation mode of dc/mc: GENERATING and, the operation of the system: REGENERATIVE BRAKING

$E_a = V_t + R_a I_a = 100 + 0.5 \times 100 = 150$ V //

$\frac{E_{a2}}{E_{a1}} = \frac{n_2}{n_1} \Rightarrow \frac{150}{50} = \frac{n_2}{477.5} \Big|_{I_f\ \text{cnst}}$

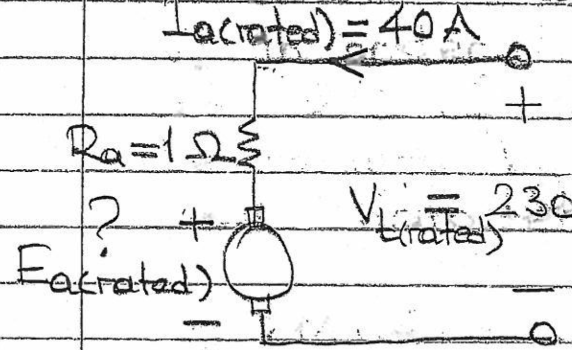
$\therefore n_2 = 1432.5$ rpm //



Example A 230 V, 40 A, 1350 rpm dc motor has an armature resistance of 1.0 Ω. Field current is supplied from a separate dc source and kept constant at the value corresponding to the rated conditions given above. Neglect friction and windage component.

a. Obtain the speed expression in terms of terminal voltage and load torque (substitute the numerical values of remaining variables and parameters). Plot it for $V_t = 127$ V.

$$\omega_r = \frac{V_t}{K_a\Phi_d} - \frac{R_a}{(K_a\Phi_d)^2} \cdot T \quad //$$



$$\omega_{r(rated)} = 1350 \times \frac{2\pi}{60} = 141.4 \text{ rad/s}$$

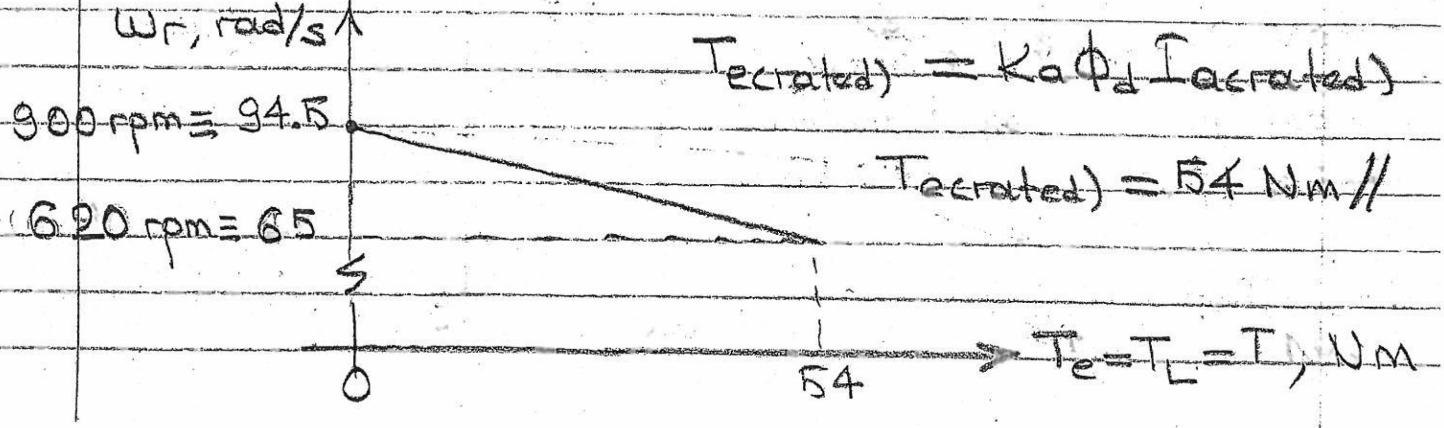
$$E_{a(rated)} = K_a\Phi_d\,\omega_{r(rated)} = V_{t(rated)} - R_a I_{a(rated)}$$

$$230 - 1 \times 40 = 190 = K_a\Phi_d \times 141.4$$

$$\therefore K_a\Phi_d = 1.344 \quad // \text{ which is cost.}$$

$$\omega_r = \frac{127}{1.344} - \frac{1.0}{(1.344)^2} \cdot T \quad //$$

$$\omega_r = 94.5 - 0.55 \cdot T \quad //$$



$$T_{e(rated)} = K_a\Phi_d I_{a(rated)}$$

$$T_{e(rated)} = 54 \text{ Nm} \quad //$$

Assume now that the speed control is achieved by armature voltage control and armature supply is a controllable one in the range from 0 to 230 V dc.

b) If the load demands a constant-torque of 20 Nm, compute V_t in order to drive the load at 2/3 of rated speed.

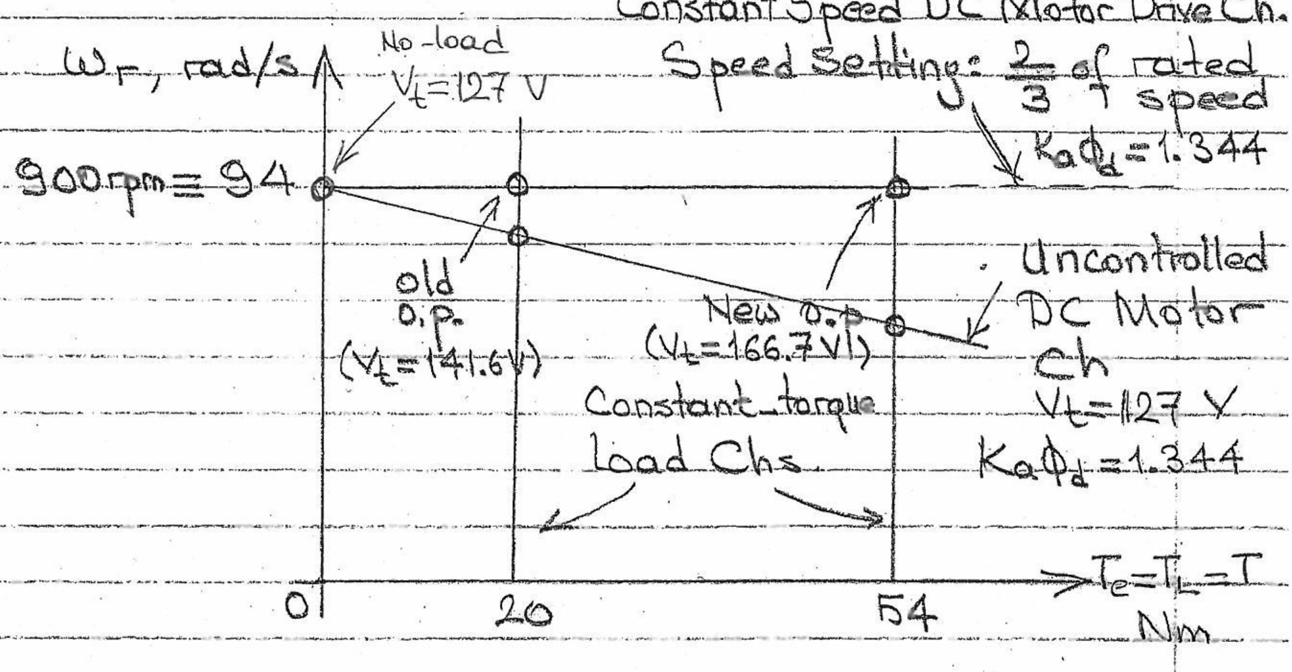
$$\frac{2}{3} \times 141.4 = \frac{V_t}{1.344} - \frac{1.0}{(1.344)^2} \cdot 20$$

$$\therefore \quad V_t = 141.6 \text{ V} \;//$$

c) If the constant-torque load in (b) is increased to 54 Nm, calculate new V_t in order to keep the speed constant at 2/3 of rated speed. Summarize the results by plotting motor, drive and load characteristics on a common graph paper.

$$\frac{2}{3} \times 141.4 = \frac{V_t}{1.344} - \frac{1.0}{(1.344)^2} \cdot 54$$

$$\therefore \; V_t = 166.7 \text{ V} \;//$$



d) Now if the shaft speed should be increased temporarily 50% above the rated speed while the M/C is operating at no-load and at rated voltage, find the percentage change in direct-axis flux, Φ_d.
What do we call this technique?

$$\text{Old } \omega_0 = \frac{230}{K_a\Phi_d} = 141.4 \text{ rad/s}$$

$$\text{New } \omega_0' = 1.5 \times 141.4 = \frac{230}{K_a\Phi_d'}$$

$$\therefore \text{ New } K_a\Phi_d' = 1.085 \ //$$

$$\frac{K_a\Phi_d'}{K_a\Phi_d} = \frac{1.085}{1.344} = 0.8$$

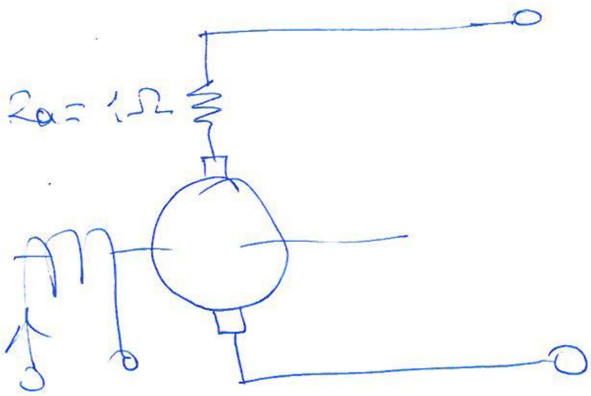
It is seen that direct-axis flux should be reduced to 80% of its rated value.

This speed control technique is known as the FIELD WEAKENING.

Ex1 Separately excited dc motor

$I_{a(rated)} = 100\,A$

$R_a = 1\,\Omega$



E_a vs I_f at 1000 RPM

$E_a = 200\, I_f \qquad I_f \leq 1.0A$

$E_a = 100\, I_f + 100 \qquad I_f > 1.0A$

a) Obtain its magnetization ch at 500 rpm

Since $E_a = K_a \phi_d \omega_r$

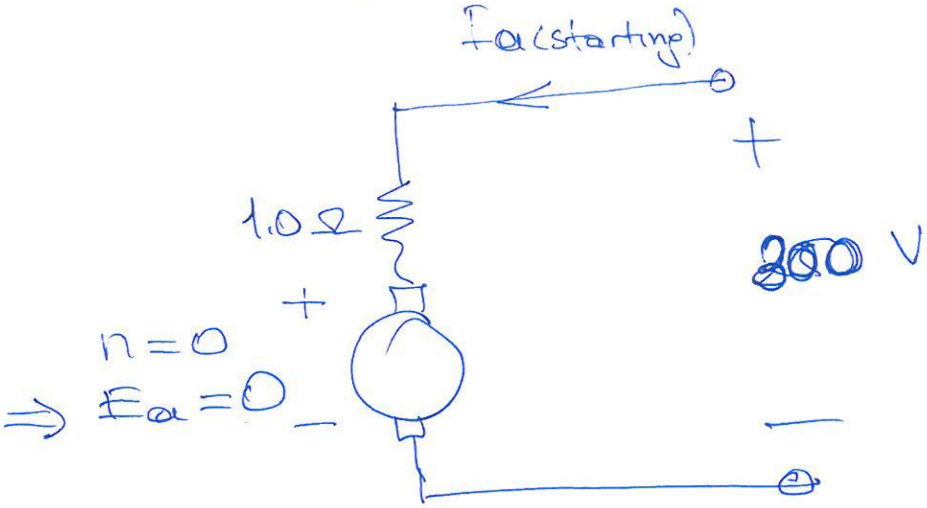
then $$\left.\frac{E_{a_1}}{E_{a_2}}\right|_{\substack{I_f\text{-cnst}\\ \phi_d\text{-cnst}}} = \left.\frac{\omega_{r_1}}{\omega_{r_2}}\right|_{\substack{I_f\text{-cnst}\\ \phi_d\text{-cnst}}} = \left.\frac{n_1}{n_2}\right|_{\substack{I_f\text{-cnst}\\ \phi_d\text{-cnst}}}$$

$$\Rightarrow E_{a_2} = \frac{n_2}{n_1} E_{a_1} = \frac{500}{1000} E_{a_1} = 0.5\, E_{a_1}$$

New Ch: $E_a = 100\, I_f \qquad I_f \leq 1.0\,A$

$E_a = 50\, I_f + 50 \qquad I_f > 1.0\,A$

b) If it is started by direct on starting technique compute initial value of starting current by assuming that $V_{t(rated)} = 300\ V$ and $I_f = 1.0\ A$.



$$V_t = E_a + I_a R_a \quad \text{(for Motoring Operation)}$$

$$300 = 0 + I_a \times 1.0$$

$$\Rightarrow I_a = 300\ A \gg I_{a(rated)} \quad //$$

Compute I_a when the speed reaches 500 RPM.

at 500 rpm E_a is 100 V.

$$\therefore \quad 300 = 100 + I_a \times 1.0$$

$$I_a = \frac{300 - 100}{1.0} = 200\ A \quad //$$

Compute I_a at 1000 rpm.

at 1000 rpm E_a is 200 V

$$300 = 200 + I_a \times 1.0$$

$$\therefore \quad I_a = \frac{300 - 200}{1.0} = 100\ A = I_{a(rated)} \quad //$$

c) Compute T_e at $n = 1000$ rpm and $I_f = 1.0$ A

at 1000 rpm and $I_f = 1.0$ A : $E_a = 200$ V

$$E_a = K_a \phi_d \omega_r$$

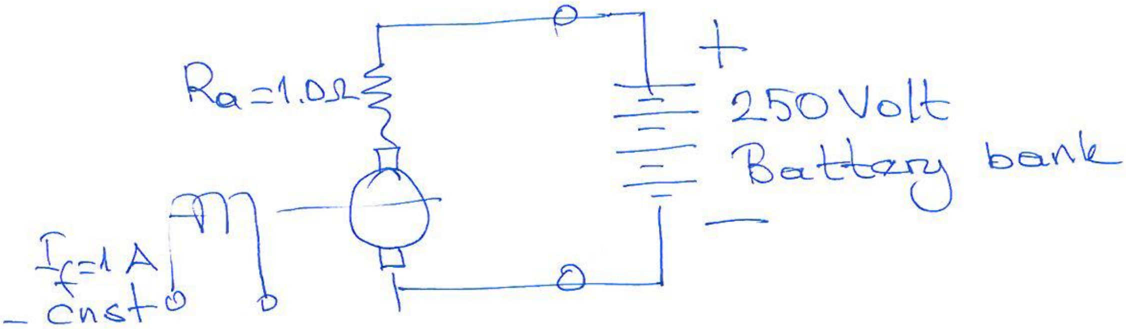
$$200 = K_a \phi_d \times 1000 \frac{2\pi}{60}$$

$$\therefore K_a \phi_d = 1.91$$

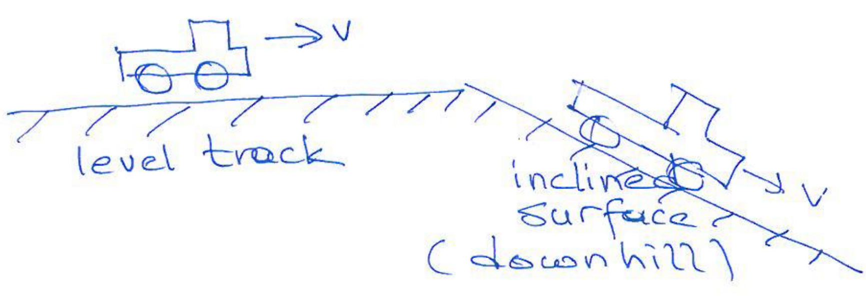
$$T_e = K_a \phi_d I_a$$

$$T_e = 1.91 \times 100 = 191 \text{ Nm}$$

d) Let us drive an electric car by using the separately excited dc motor given above.

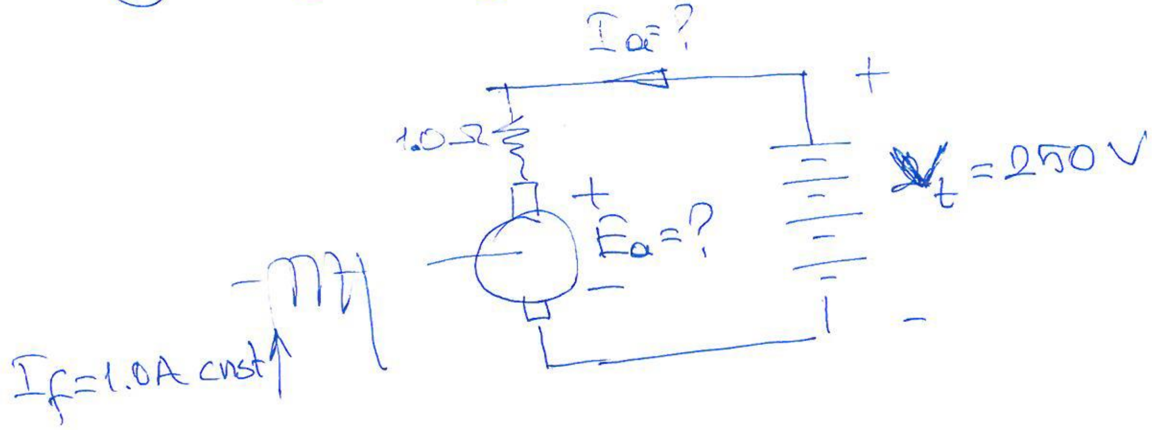


Consider the following track on the ~~motor~~ road.



(4)

Compute the maximum speed of the motor on the level track by neglecting friction and windage losses.



Since T_L owing to gravitational force on a level track is zero and $T_{f\&w} = 0$

then $T_e = T_L + T_{f\&w} = 0$ Nm

$T_e = K_a \Phi_d I_a \Rightarrow I_a = 0$ //

$V_t = E_a + I_a R_a$

$250 = E_a + 0$

$\therefore E_a = 250$ V //

at $I_f = 1.0$ A $\quad E_{a_2} = \frac{N_2}{1000\,rpm} \times 200$ Volts

$250 = N_2 \times 0.2$

$\Rightarrow N_2 = 1250$ rpm // max motor speed

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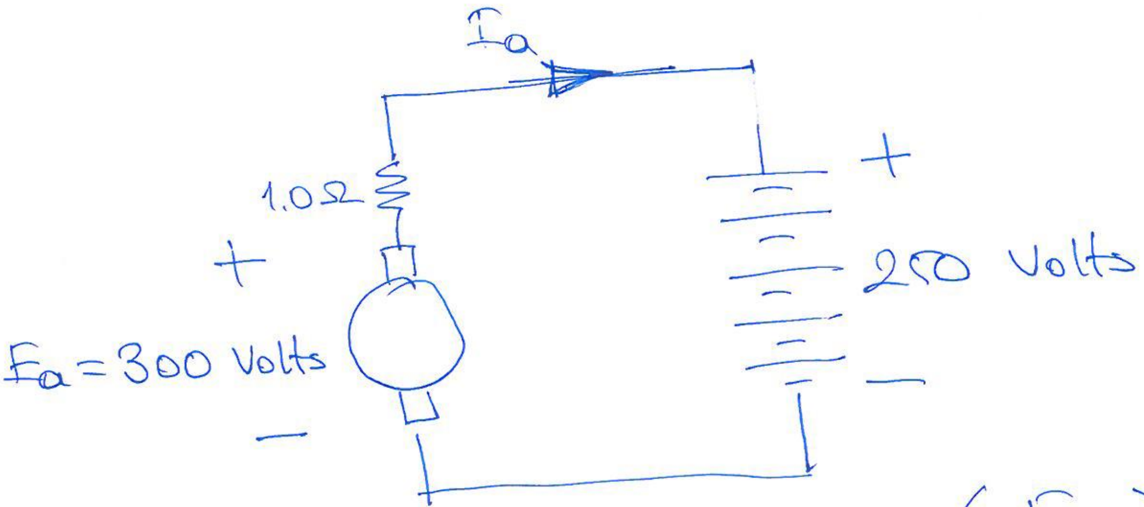
Assume now that the electric vehicle moves downhill at a constant speed (Constant motor speed is 1500 rpm). Identify the operation mode of the dc machine. Compute electromechanical torque and electromechanical power. ~~converted~~.

At 1500 rpm and $I_f = 1.0$ A

$$E_a = \frac{1500}{1000} \times 200 = 300 \text{ Volts}$$



Armature current reverses ($E_a > V_t$)

$$I_a = \frac{V_t - E_a}{R_a} = \frac{250 - 300}{1.0} = -50 \text{ A}$$

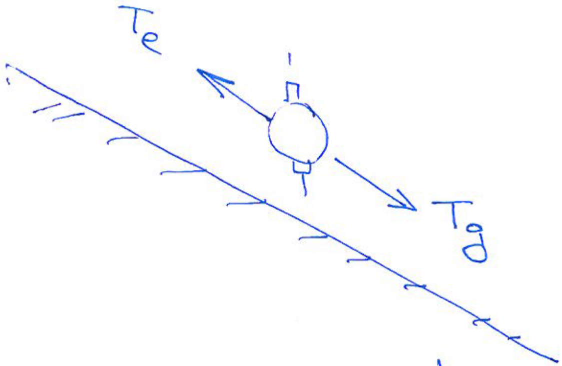
Electromechanical Power, $P_e = E_a I_a = -300 \times 50 = -15000$ W

(−) sign : Mechanical Power Converted to Electrical Form.

DC M/C operates in GENERATING Mode.

$$T_e = K_a \Phi_d \cancel{\omega_m} I_a$$

$$T_e = 1.91 \times (-50) = -95.5 \text{ Nm}$$



$T_g = T_e$

$T_g = F_{gi} \cdot r$

1 rev ≡ $2\pi r$ meters

1 rpm ≡ $2\pi r n$ m/min

1 rpm ≡ $\frac{2\pi r n}{60}$ m/s

1 rpm = $\frac{2\pi}{60}$ rad/s

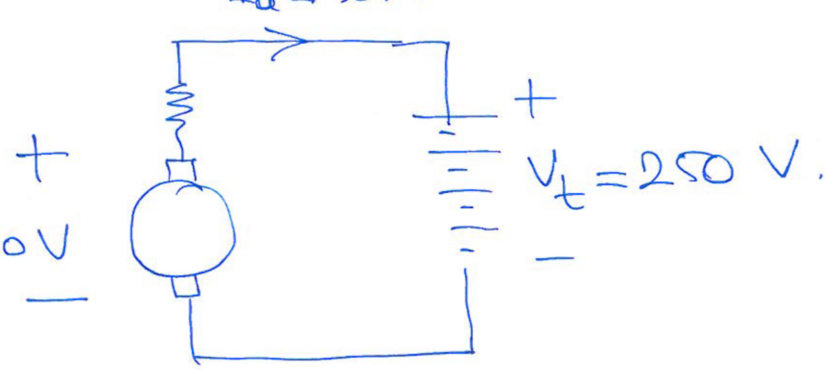
This technique is known as the ELECTRIC BRAKING.

Regenerative Braking.

T_g owing to gravitational force tends to move the electric vehicle downhill.

What will happen if one increases I_f from 1.0 A to 1.5 A ?

T_g is cnst $\Longrightarrow$ I_a and hence E_a should remain cnst.



Since $I_f > 1.0A$ then $E_a = 100 I_f + 100 \Big|_{n = 1000\ rpm}$

New $E_a = 100 \times 1.5 + 100 = 250$ volts if the m/c would run at 1000 rpm.

However E_a should remain cnst at 300 V

$$\therefore \quad \frac{n_2}{n_1} = \frac{E_{a_1}}{E_{a_2}}$$

$$\frac{n_2}{1000} = \frac{300}{250}$$

New speed, $n_2 = 1200$ rpm //

If one increases I_f and hence ϕ_d electric vehicle starts to move downhill at a lower speed.

Repeat the problem by assuming that I_f is reduced from 1.0 A to 0.5 A.