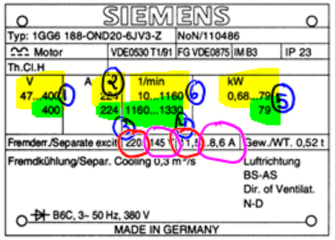
Example 3-2: Nameplate and M/n characteristic



Armature adjustment area

Field weakening ↓ $n_{max}: 1330\,\text{min}^{-1}$

Figure 3.16: Nameplate of a DC motor (Siemens AG)

a. Use the rating plate in figure 3.16 to determine the rated values for armature voltage and current, excitation voltage and current, as well as power and speed.
b. Determine the armature resistance from the nominal data.
c. Determine from the data for $n = 1160\,\text{min}^{-1}$ and $n = 1330\,\text{min}^{-1}$ the excitation resistance and explain the difference. What are the no-load speeds at:
   c1. $U_A = 400\,\text{V} / U_f = 220\,\text{V}$ and
   c2. $U_A = 400\,\text{V} / U_f = 145\,\text{V}$?
d. Sketch the speed-torque characteristics for
   d1. $U_A = 400\,\text{V} / U_f = 220\,\text{V}$ and
   d2. $U_A = 400\,\text{V} / U_f = 145\,\text{V}$.

Armature adjustment area

Field - weakening operation

a)

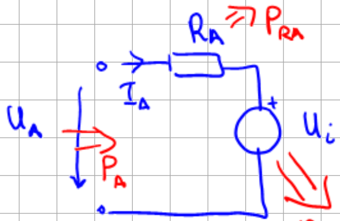
$U_{AN} = 400\,\text{V}$ ① $I_{AN} = 224\,\text{A}$ ②

$U_{FN} = 220\,\text{V}$ ③ $I_{FN} = 11{,}5$ ④

$P_N = 79\,\text{kW}$ ⑤ $n_N = 1160\,\text{min}^{-1}$ ⑥

$(n_{max} = 1330\,\text{min}^{-1})$

b) R_A $(P_{Fric} \to 0,\ P_B \to 0)$



$P_{mech} + P_{Fric} \approx P_{mech}$

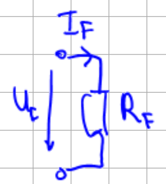
$$R_A = \frac{U_A - U_i}{I_A} \underset{\substack{\uparrow \\ \text{For nominal point}}}{=} \frac{U_{AN} - \overset{?}{U_{iN}}}{I_{AN}} = \frac{400\,\text{V} - 352.7\,\text{V}}{224\,\text{A}} = 0.211\,\Omega$$

$P_{mech} = P_N = U_{iN} \cdot I_{AN}$

$$U_{iN} = \frac{P_N}{I_{AN}} = \frac{79000\,\text{W}}{224\,\text{A}} = 352.7\,\text{V}$$

c) R_F @ $1160\,min^{-1}$?

R_F @ $1330\,min^{-1}$



$$R_F = \frac{U_F}{I_F} \begin{cases} n = 1160\,min^{-1} \rightarrow R_F = \dfrac{220V}{11.5A} = 19.1\,\Omega \\ n = 1330\,min^{-1} \rightarrow R_F = \dfrac{145V}{8.6A} = 16.86\,\Omega \end{cases} \text{Difference ?}$$

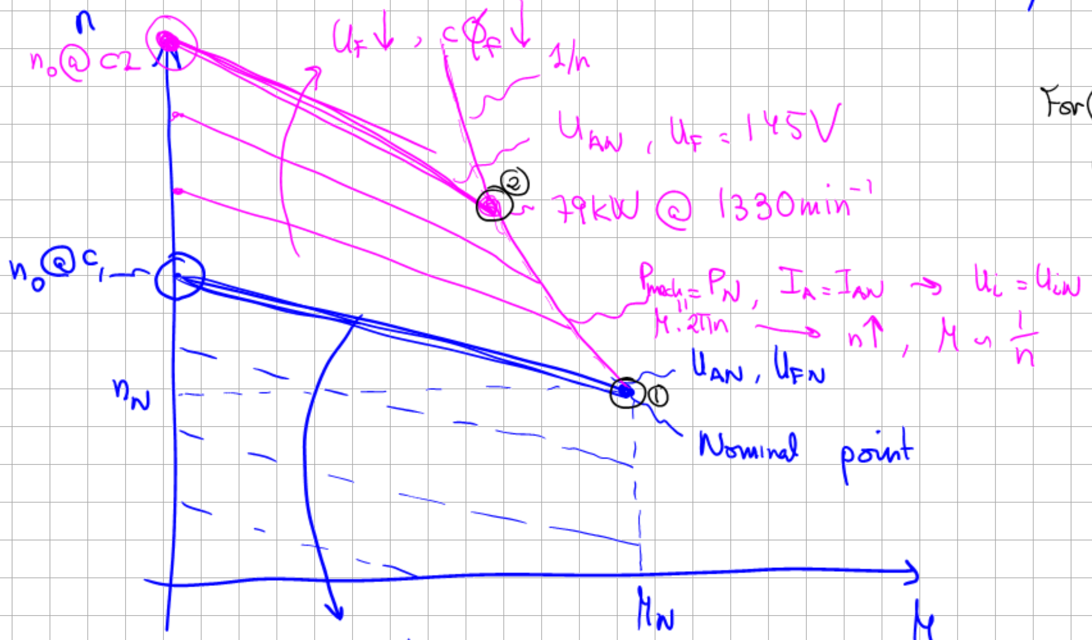
$I_F \uparrow \rightarrow P_{RF} \uparrow \rightarrow T \uparrow$

$\rightarrow R_F \uparrow$

$(\Delta T = 33k)$

c) No-Load speed n_0

(No-load $\rightarrow M = 0 \rightarrow M_i = M + M_{Fric} \approx 0$)



$U_A \downarrow$, $U_F = U_{FN}$ $(c\Phi_F = c\Phi_{FN})$

For ⓓ only M in points ① and ② are missing.

$$M = \frac{P_{mech}}{2\pi n}$$

① 650 Nm

② 567 Nm

c1) $M = 0$ (no-load) $\rightarrow I_A = 0 \rightarrow U_{AN}\ U_i = c\phi_{FN} \cdot 2\pi \cdot n_0$ $\quad U_F = U_{FN} \rightarrow c\phi_F = c\phi_{FN}$

$U_A = U_{AN}$

$M+M_{Fric}$

$$\boxed{\begin{aligned} M_i &\approx M = c\phi_F \cdot I_A \\ U_i &= c\phi_F \cdot 2\pi \cdot n \\ U_A &= R_A \cdot I_A + U_i \ (+U_B) \end{aligned}}$$

$$n_0 = \frac{U_{AN}}{c\phi_{FN} \cdot 2\pi} \overset{1}{=} \frac{U_{AN}}{\frac{U_{iN}}{\cancel{2\pi} n_N} \cdot \cancel{2\pi}} = n_N \cdot \frac{U_{AN}}{U_{iN}}$$

For the nominal point: $U_{iN} = c\phi_{FN} \cdot 2\pi n_N \rightarrow c\phi_{FN} \overset{1}{=} \frac{U_{iN}}{2\pi n_N}$

$$n_0 = 1160\ min^{-1} \cdot \frac{400V}{\underbrace{352.7V}_{a}} = \underline{\underline{1315.6\ min^{-1}}}$$

c2) $M = 0 \rightarrow I_A = 0 \rightarrow U_{AN} = U_i = c\phi_F \cdot 2\pi n_0$ $\quad U_F = 145V \neq U_{FN} \rightarrow c\phi_F \neq c\phi_{FN}$

$$n_0 = \frac{U_{AN}}{c\phi_F \cdot 2\pi} \overset{2}{=} \frac{U_{AN}}{\frac{U_{iN}}{2\pi n_{max}} \cdot \cancel{2\pi}} = n_{max} \cdot \frac{U_{AN}}{U_{iN}} = 1330\ min^{-1} \cdot \frac{400V}{352.7V} = \underline{\underline{1508\ min^{-1}}}$$

For the op point @ $U_F = 145V$, $P = 79kW$, $n_{max} = 1330\ min^{-1}$

$$U_i = \frac{P}{I_A} = \frac{P_N}{I_{AN}} = U_{iN} = c\phi_F 2\pi\, n_{max} \rightarrow c\phi_F \overset{2}{=} \frac{U_{iN}}{2\pi n_{max}}$$

Example 3-4: Regulated DC Motor

A DC motor with the following nominal data is given: Nominal data 3 kW / 1500 min^{-1}, Armature: 220 V / 14.5 A, Excitation circuit 220 V / 1.2 A. The armature and excitation circuits of the speed-controlled motor are each fed via their own power converter, with the excitation current being regulated in inverse proportion to the speed from the rated speed. ($I_f/I_{fN} = n_N/n$ for $n > n_N$) With the exception of the Joule heat losses, all losses can be neglected. $\rightarrow P_{fric} = P_B = 0$

a. Determine the armature and excitation resistance.
b. What is the efficiency and the nominal torque at the nominal point?
c. At rated speed, the motor is loaded with half the rated torque. What are the values for the armature voltage and the excitation voltage?
d. The speed setpoint is now increased to 150% of the nominal speed, whereby the motor is now only loaded with 25% of the nominal torque. What are the values for the armature voltage and the excitation voltage?
e. What is the maximum torque that the motor can deliver at this speed if the electrical ratings can not be exceeded?

$P_N = 3\,kW$

$n_N = 1500\,min^{-1}$

$\begin{cases} U_{AN} = 220V \\ I_{AN} = 14.5A \end{cases}$

$\begin{cases} U_{FN} = 220V \\ I_{FN} = 1.2A \end{cases}$ $\rightarrow n > n_N \rightarrow I_F = I_{FN} \cdot \frac{1}{n/n_N} \rightarrow$ Field-weakening

$\left(U_F = U_{FN} \cdot \frac{1}{n/n_N} \quad \& \quad c\phi_F = c\phi_{FN} \cdot \frac{1}{n/n_N} \right)$

$n \leq n_N \rightarrow I_F = I_{FN} \rightarrow$ Armature adjustment

$\left(U_F = U_{FN} \quad \& \quad c\phi_F = c\phi_{FN} \right)$

a) R_A, R_F?

$$R_F = \frac{U_{FN}}{I_{FN}} = \frac{220V}{1.2A} = \underline{\underline{183.33\,\Omega}}$$

$$R_A = \frac{U_{AN} - U_{iN}}{I_{AN}} = \frac{220V - 206.9V}{14.5A} = \underline{\underline{0.903\,\Omega}}$$

$$U_{iN} = \frac{P_N}{I_{AN}} = \frac{3000\,W}{14.5A} = 206.9V$$

b) η_N, M_N

$$\eta_N = \frac{P_{out}}{P_{in}} = \frac{P_N^{(mech)}}{U_{AN} \cdot I_{AN} + U_{FN} \cdot I_{FN}} = \frac{3000\,W}{220V \cdot 14.5A + 220V \cdot 1.2A} = \underline{\underline{86.8\%}}$$

$$M_N = \frac{P_N}{2\pi n_N} = \frac{3000\,W}{2\pi \cdot \frac{1500}{60}\,s^{-1}} = \underline{\underline{19.1\,Nm}}$$

c) $n = n_N$ $\quad \frac{1}{4} n_N$ $\qquad M = \frac{1}{2} M_N \qquad U_A, U_F$?

$$M_i \approx M = c\Phi_F \cdot I_A$$
$$U_i = c\Phi_F \cdot 2\pi n$$
$$U_A = U_i + R_A \cdot I_A$$

$$U_F = U_{FN} = 220V \rightarrow c\Phi_F = c\Phi_{FN}$$

$$M = c\Phi_{FN} \cdot I_A = \frac{1}{2} M_N = \frac{1}{2}\left(c\Phi_{FN} \cdot I_{AN}\right)$$

$$\Rightarrow \quad I_A = \frac{I_{AN}}{2}$$

$$U_i = c\Phi_{FN} \cdot 2\pi \frac{n_N}{4} = U_{iN}/4$$

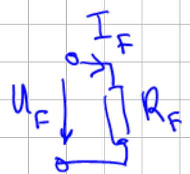
$$U_A = U_{iN} + R_A I_A = \frac{206.9V}{4} + 0.903\Omega \cdot \frac{14.5A}{2} = 213.44V \quad 58.3V$$

8.5.2024

d) $n = 1.5 n_N \qquad M = \frac{1}{4} M_N \qquad U_A, U_F$?

$$n > n_N \rightarrow I_F = I_{FN} \frac{1}{n/n_N} \longrightarrow U_F = U_{FN} \cdot \frac{1}{n/n_N} = \frac{U_{FN}}{1.5} = \frac{220V}{1.5} = 146.7V$$

$n/n_N = 1.5$



$$c\Phi_F = \frac{c\Phi_{FN}}{1.5} \longrightarrow U_i = c\Phi_F \cdot 2\pi n = \frac{c\Phi_{FN}}{\cancel{1.5}} \cdot 2\pi \cdot \cancel{1.5} n_N = U_{iN}$$

- $n \leq n_N \rightarrow$ Armature adjustment area $\rightarrow U_F = U_{FN} \rightarrow c\phi_F = c\phi_{FN} \rightarrow U_i \sim n$
- $n > n_N \rightarrow$ Field-weakening area $\rightarrow U_F \sim \frac{1}{n/n_N} \rightarrow c\phi_F \sim \frac{1}{n/n_N}$ $\quad U_i = \text{constant}$, $U_A \approx \text{constant}$

$$U_A = U_i + R_A \cdot I_A$$

I_A?

$$M = c\phi_F \cdot I_A = \frac{c\phi_{FN}}{1.5} \cdot I_A = 0.25 \cdot M_N = 0.25 \cdot c\phi_{FN} \cdot I_{AN}$$

$$\frac{\cancel{c\phi_{FN}}}{1.5} I_A = 0.25 \cdot \cancel{c\phi_{FN}} \cdot I_{AN} \rightarrow I_A = 1.5 \cdot 0.25\, I_{AN} = 5.437A$$

$$U_A = U_{iN} + R_A \cdot I_A = 206.9V + 0.903\Omega \cdot 5.437A = 211.8V$$

e) $n = 1.5\, n_N \rightarrow M_{max}? \rightarrow I_A = I_{AN} = 14.5\,A$

We are looking for the max torque without exceeding the el. limit

Max. torque $\Rightarrow$ max. armature current

$\Downarrow$

I_{AN}

$\downarrow$

$U_i = U_{iN}$

$$c\phi_F = \frac{c\phi_{FN}}{1.5} = \frac{c\phi_{FN}}{n/n_N}$$

$$M_{max} = c\phi_F \cdot I_A = \underbrace{\frac{c\phi_{FN}}{1.5} \cdot I_{AN}}_{= M_N} = \frac{M_N}{1.5} = \frac{M_N}{n/n_N}$$

$$M_{max} = \frac{19.1\,Nm}{1.5} = 12.733\,Nm$$

2 additional problems in e-Learning

- Example 3-3 a)

Example 3-3: Separately excited DC motor

Given is a machine with the nominal data 10 kW / 1300 min^{-1}, armature: 440 V / 25 A, excitation circuit 200 V / 2 A. The brush voltage drop is estimated as 1 V per brush.

In a no-load test (externally driven machine with an open armature circuit, i.e. $I_A = 0$), at 1000 min^{-1} the armature voltage U_A was measured as a function of the excitation current I_f (figure 3.17). Iron losses and armature reaction can be neglected. The friction torque can be assumed to be constant.

a. Provide the power flow diagram for the nominal point with the numerical values for all losses (including friction and brush losses). What is the efficiency at the nominal point? Sketch the equivalent circuit with all numerical values for the nominal point.

No-load test @ 1000 min^{-1}

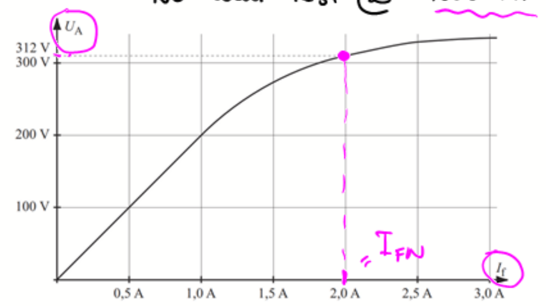


Figure 3.17: Saturation curve (measured values)

b. What is the rotational speed when the DC machine is completely unloaded starting from the rated point? (i.e. $M_{Last} = 0$, but $M_{Fric} > 0$)

c. Assuming that the calculated equivalent circuit data are valid for the machine at operating temperature. What speed would be reached during operation at rated voltages if the machine were loaded with the rated torque when cold?

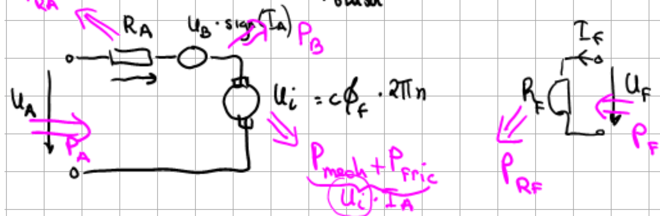
Note: $\vartheta_U = 20°C$; $\vartheta_W = 120°C$; $\alpha_{Cu,20} = 0.004\,K^{-1}$; $R(\vartheta) = R_{20}(1 + \alpha_{Cu,20} \cdot \Delta\vartheta)$

$P_N = 10\,kW$ $\qquad M_{Fric} = \text{const.}$

$n_N = 1300\,min^{-1}$

$\begin{cases} U_{AN} = 440V \\ I_{AN} = 25A \end{cases}$ $\qquad U_{FN} = 200V$, $I_{FN} = 2A$

$U_B = 2\,\text{brushes} \cdot 1V/\text{brush} = 2V$



No-load $\rightarrow I_A = 0 \Rightarrow U_A = U_i$

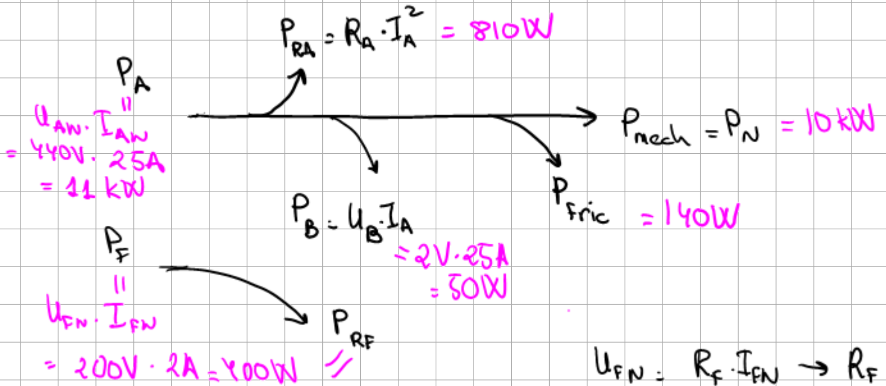
$\underbrace{U_i \text{ @ } n = 1000\,min^{-1}} = f(I_F)$

$c\phi_F = \dfrac{U_i}{2\pi \cdot 1000\,min^{-1}} = f(I_F)$

a) Power flow diagram @ nominal point (with values)

Equivalent circuit elements

R_N?



$U_{FN} = R_F \cdot I_{FN} \rightarrow R_F = \dfrac{U_{FN}}{I_{FN}} = \dfrac{200\,V}{2A} = 100\,\Omega$

$U_{iN} = \underbrace{U_i\,(I_f = I_{FN})}_{312V} \cdot \dfrac{1300\,min^{-1}}{1000\,min^{-1}} = 405.6V$

$$P_{i,mech} = \underbrace{P_{mech}}_{10\,kW} + P_{fric} = U_{iN} \cdot I_{AN} = 405.6V \cdot 25A = 10.14\ kW$$

$$\Rightarrow P_{fric} = 10140W - 10000W = 140W$$

$$R_A = \frac{U_{AN} - U_{iN} - U_B}{I_{AN}} = \frac{440V - 405.6V - 2V}{25A} = \underline{\underline{1.296\,\Omega}}$$

$$P_{RA} = R_A \cdot I_A^2 = 1.296\Omega \cdot (25A)^2 = 810W$$

$$\eta = \frac{P_N}{P_{AN} + P_{FW}} = \frac{10000W}{11000W + 400W} = \underline{\underline{87.7\%}}$$