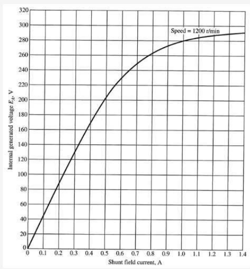
Assignment 3 - DC Motors

Wednesday, February 17, 2016 3:43 PM

(10 pts)
A shunt DC motor is fed from a 225 V DC source. The field coil has a resistance of 222 Ω. The total armature resistance (including the contact resistance of the brushes against the segments of the commutator) is 0.13 Ω. The field adjustable resistor is set at 412 Ω. The motor is rated for 25 hp. The motor has compensation windings.

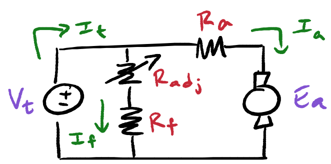
Magnetization characteristic $E_a = f(I_f)$:



Field Current (A)	Ea (V) at 1200rpm
0	3.0305
0.4	170.2049
0.5	204.4685
0.6	230.4445
0.7	249.8647
0.8	263.966
0.9	273.8616
1	280.5412
1.1	285.1179
1.2	288.0247
1.3	290.2513
1.4	291.983

(a) What is the start up armature current? (A) A

(b) What is the start up torque, in $N.m$? $N.m$



$R_a = 0.13\Omega$
$R_f = 222\Omega$
$R_{adj} = 412\Omega$
$V_t = 225V$

@ start up $E_a = \emptyset$ ∴

$$I_a^{start} = \frac{V_t}{R_a} \rightarrow \boxed{I_a^{start} = 1731\,A}$$

$$I_f = \frac{V_t}{R_{adj} + R_f} \rightarrow I_f = 354.9\,mA$$

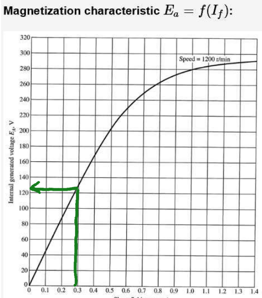
compensation windings ∴ $I_f^* = I_f \rightarrow E_a^{1200} = 145V$

$$E_a = k\phi\omega \rightarrow k\phi = \frac{E_a^{1200}}{1200\frac{2\pi}{60}}$$

$$\tau = k\phi I_a \rightarrow \tau = \frac{145}{1200\frac{2\pi}{60}} 1731 = \boxed{1997\,Nm}$$

(10 pts)
A shunt DC motor is fed from a 190 V DC source, and let run idling (no mechanical load). The field coil has a resistance of 180 Ω. The total armature resistance (including the contact resistance of the brushes against the segments of the commutator) is 0.19 Ω. The field adjustable resistor is set at 468 Ω. The total rotational losses have been measured at full load as 1800 W. The motor has compensation windings.

Magnetization characteristic $E_a = f(I_f)$:



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1.2	288.0247
1.3	290.2513
1.4	291.983

(c) What is the idling speed? RPM

(d) What is the terminal idling current, in amps? A

$$P_{conv} = I_a E_a \rightarrow 1800 = I_a E_a^*$$

$$E_a = V_t - I_aR_a \longrightarrow E_a^n = 190 - I_a\, 0.19$$

$$\longrightarrow E_a^n = 188.2,\quad I_a = 9.565$$

$$I_f = \frac{V_t}{R_f + R_{adj}} \longrightarrow I_f = 293\,\text{mA}$$

$$\hookrightarrow E_a^{1200} = 125\,V$$

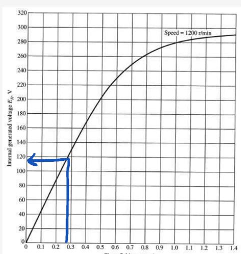
$$\frac{E_a^n}{n} = \frac{E_a^{1200}}{1200}$$

$$\longrightarrow n = \frac{1200 \cdot 188.2}{125} = \boxed{1807\ RPM}$$

$$I_t = I_a + I_f \longrightarrow \boxed{I_t = 9.858\,A}$$

(10 pts)
A shunt DC motor is fed from a 173 V DC source. The field coil has a resistance of 204 Ω. The total armature resistance (including the contact resistance of the brushes against the segments of the commutator) is 0.19 Ω. The field adjusting resistor is set at 418 Ω. The motor is rated for 29 hp. The total rotational losses have been measured at full load as 900 W. The motor has compensation windings. You load this motor to its full capacity.

Magnetization characteristic $E_a = f(I_f)$**:**



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(e) What is the full load speed, in rpm? ______ RPM

(f) What is the full load terminal current, in amps? ______ A

(g) What is the speed regulation between idling and full load in percent? ______ %

(p) What is the torque at the mechanical load, in N.m? ______ $N.m$

$$P_{out} = 29\,hp,\quad P_{rot} = 900\,W$$

$$\left.\begin{aligned} &P_{conv} = P_{out} + P_{rot} = E_a^n I_a \\ &E_a^n = V_t - I_aR_a \end{aligned}\right\} \quad E_a^n = 143.1\,V,\quad I_a = 157.5\,A$$

$$I_f = \frac{V_t}{R_{adj} + R_f} \longrightarrow I_f = 278.1\,\text{mA}$$

$$\hookrightarrow E_a^{1200} = 119\,V$$

$$n_{\text{full load}} = \frac{1200 \cdot 143.1}{119} = \boxed{1443\ RPM}$$

$$I_t = I_f + I_a \longrightarrow \boxed{I_t = 147.8\,A}$$

$$\tau = \frac{E_a^n I_a}{n\frac{2\pi}{60}} \longrightarrow \boxed{149.2\,Nm}$$

@ idling $P_{out} = \varnothing \quad \therefore \quad P_{conv} = 900$

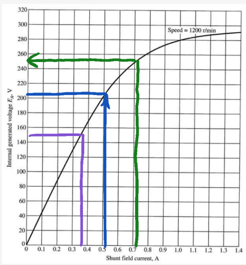
$$\left.\begin{aligned} &E_a^{idling} I_a = 900 \\ &E_a^{idling} = 173 - I_a\, 0.19 \end{aligned}\right\} \quad I_a = 5.232\,A,\quad E_a^{idling} = 172\,V$$

$$n_{idling} = \frac{1200(172)}{119} = 1734 \text{ RPM}$$

$$\%SR = \frac{n_{idling} - n_{load}}{n_{load}} 100 = \boxed{20\%}$$

(10 pts)
A shunt DC motor is fed from a 289 V DC source, and let run idling (no mechanical load). The field coil has a resistance of 242 Ω. The total armature resistance (including the contact resistance of the brushes against the segments of the commutator) is 0.2 Ω. The field adjusting resistor is set at 326 Ω. The motor is rated for 12 hp. The total rotational losses have been measured at full load as 1300 W. The motor has compensation winding. 281.722 0.508803 207.485 1629.36 289 242 326 568

Magnetization characteristic $E_a = f(I_f)$:



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1.2	288.0247
1.3	290.2513
1.4	291.983

(h) What is the full load speed, in rpm? RPM

If the field adjustable resistor can be set at any value between 80 Ω and 480 Ω,

(i) What is the maximum speed, in rpm, of the motor at full load. RPM

(j) What is the minimum speed, in rpm, of the motor at full load. RPM

(k) What is the maximum speed, in rpm, idling. RPM

(l) What is the minimum speed, in rpm, idling. RPM

$$1300 + 12(746) = I_a E_a^n$$
$$E_a^n = 289 - I_a(0.2)$$

$$E_a^n = 281.7V$$
$$I_a = 36.39A$$

$$I_f = \frac{289}{326 + 242} = 508.8mA$$
$$\hookrightarrow E_a^{1200} = 205V$$

$$n = \frac{1200 \cdot E_a^n}{E_a^{1200}} \rightarrow n = \boxed{1649 RPM}$$

full load $\therefore P_{conv} = 1300 + 12(746)$

$\hookrightarrow E_a^n = 281.7V$

$R_{adj} \uparrow \; n \uparrow \; \therefore \; n_{max}$ @ $R_f = 480\Omega$

$$\hookrightarrow I_f = \frac{289}{242+480} = 400 \text{ mA} \rightarrow E_a^{1200} = 170V$$

$$n_{max} = \frac{1200 \cdot 281.7}{170} = \boxed{1988 RPM}$$

n_{min} @ $R_f = 80\Omega$

$$I_f = \frac{289}{242+80} = 898mA \rightarrow E_a^{1200} = 275 V$$

$$n_{max} = \frac{1200(281.7)}{275} = \boxed{1229 RPM}$$

idling $\therefore P_{out} = \emptyset \; \therefore \; P_{conv} = 1300$

$$\left.\begin{aligned} 1300 &= I_a E_a^n \\ E_a^n &= 289 - I_a(0.2) \end{aligned}\right\} \begin{aligned} E_a^n &= 288.1V \\ I_a &= 4.512A \end{aligned}$$

$$1200 \cdot 288.1$$

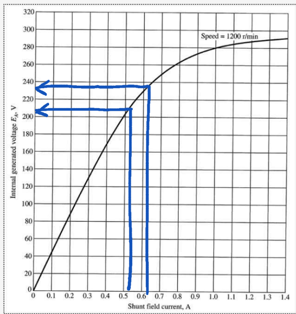
$E_a^n = 289 - I_a(0.2)$ } $E_a = 288.1V$, $I_a = 4.512A$

$$n_{max} = \frac{1200 \cdot 288.1}{170} = \boxed{2034\ RPM}$$

$$n_{min} = \frac{1200 \cdot 288.1}{275} = \boxed{1257RPM}$$

(10 pts)
A shunt DC motor is fed from a 212 V DC source. The field coil has a resistance of 234 Ω. The total armature resistance (including the contact resistance of the brushes against the segments of the commutator) is 0.23 Ω. The field adjustable resistor is set at 105 Ω. The motor is rated for 14 hp. The total rotational losses have been measured at full load as 1050 W. The motor has compensation windings that can be deactivated (academic). When the compensation windings are deactivated, the armature reaction is 550 A when the armature current is 102 A. The field coil has $N_f = 2950$ turns per pole. Compute both with and without compensation winding, the full load speed in rpm.

Magnetization characteristic $E_a = f(I_f)$:



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(h) With compensation winding, what is the full load speed, in rpm? RPM

(x) Wihout compensation winding, what is the full load speed, in rpm? RPM

$14(746) + 1050 = E_a^n I_a$
$E_a^n = 212 - I_a(0.23)$ } $E_a^n = 198.7$, $I_a = 57.85$

$$I_f = \frac{212}{105+234} = 625mA$$

$\hookrightarrow E_a^{1200} = 235V$

$$n = \frac{1200 \cdot 198.7}{235} = \boxed{1015\ RPM}$$

with compensation windings

$$I_f^* = I_f - \frac{\frac{MMF}{I_{ar}}}{N_f} I_a$$

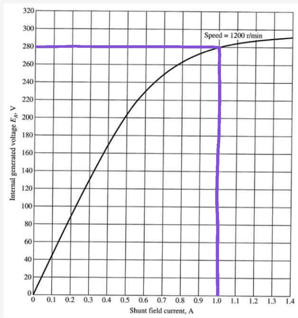
$$\hookrightarrow I_f^* = 625mA - \frac{\frac{550}{102}}{2950} 57.85 = 520mA$$

$\hookrightarrow E_a^{1200} = 205V$

$$n = \frac{1200 \cdot 198.7}{205} = \boxed{1163\ RPM}$$

(20 pts)
A long compound DC motor is fed from a 287 V DC source and its draining 19 A off the external DC source. The field coil has a resistance of 144 Ω. The total armature resistance (including the contact resistance of the brushes against the segments of the commutator) is 0.27 Ω. The field adjustable resistor is set at 139 Ω. The motor is rated for 21 hp. The total rotational losses have been measured at full load as 1000 W. The motor has compensation windings. The field coil has $N_f = 3000$ turns per pole, and the series coil has $N_s = 23$ turns per pole and $R_s = 0.03\ \Omega$.

Magnetization characteristic $E_a = f(I_f)$:



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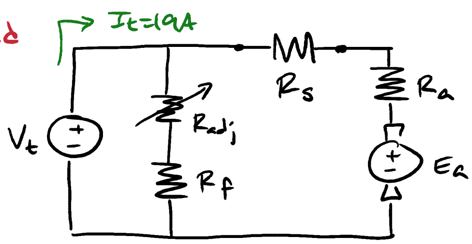
(a) What is the speed, in rpm? RPM

(b) What is the output torque, in N.m? $N.m$

(c) What is the current of the external source when the motor is fully loaded, in amps? A

(d) At full load, what is the speed, in rpm? RPM

long compound



$I_f = \frac{V_t}{R_{adj}+R_f}$ → $I_f = 1.014 A$

$I_a = I_t - I_f$ → $I_a = 17.99 A$ when I_t measured @ 19A

$E_a^n = V_t - I_a(R_a+R_s)$ → $E_a^n = 281.6 V$

$I_f^* = I_f + I_s \frac{N_s}{N_f}$ → $I_f^* = 1.152$

↳ $E_a^{1200} = 286.6V$

$n = \frac{1200\, E_a^n}{E_a^{1200}}$ → $n = \frac{1200 \cdot 281.6}{286.6} = \boxed{1179 RPM}$

$\tau = \frac{E_a^n I_a - P_{rot}}{n \frac{2\pi}{60}}$ → $\tau = \frac{281.6(17.99) - 1000}{1179 \frac{2\pi}{60}} = \boxed{34 Nm}$

when @ full load, $P_{conv} = 21(746) + 1000$

$21(746) + 1000 = I_a E_a^n$
$E_a^n = 287 - I_a(0.27 + 0.03)$
$\Big\}$ $E_a^n = 264.6$, $I_a = 58.12$

$I_t = I_a + I_f$ → $I_t = 58.12 + \frac{287}{144+139} = \boxed{63.12 A}$

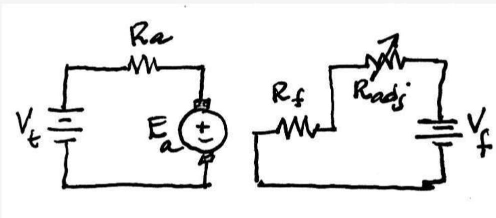
↳ $I_f = 1.014 A$ → $E_a^{1200} = 280V$

$\hookrightarrow I_f = 1.014\,A \longrightarrow E_a^{1200} = 280V$

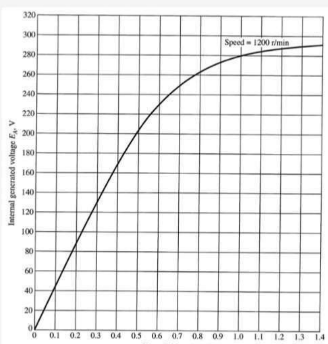
$\boxed{Q}$

(10 pts)
An independently excited DC motor whose armature is energized by an external DC source V_t, has its field excitation circuit independently energized by another DC voltage source $V_f = 273\ V$. The field adjustable resistor R_{adj} is set at $182\ \Omega$. The field coil has a resistance $R_f = 202\ \Omega$. The armature resistance is $R_a = 0.03\ \Omega$.

DC motor with independent excitation:



Magnetization characteristic $E_a = f(I_f)$**:**



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What is the idling speed, in rpm, of the motor when ...

(a) For V_t = 231 V $n_{idle} =$? RPM

(b) For V_t = 288 V $n_{idle} =$ RPM

(c) For V_t = 287 V $n_{idle} =$ RPM

$$I_f = \frac{V_f}{R_f + R_{adj}}$$

$\hookrightarrow I_f = 710.9\,mA \longrightarrow E_a^{1200} = 250V$

assuming $I_a = \phi \rightarrow E_a^n = V_t$

$V_t = 231$ $\quad n = \frac{1200}{250} \cdot 231 = \boxed{1109RPM}$

$V_t = 288$ $\quad n = \frac{1200}{250}\ 288 = \boxed{1382RPM}$

$V_t = 287$ $\quad n = \boxed{1378RPM}$

(10 pts)
A series DC motor is connected to a DC source of 236 V and its rated current is 61 A. It has a series coil with 37 turns per pole and R_s = 0.02 Ω. Its armature resistance is 0.03 Ω. The magnetization curve, measured at 900 rpm, and expressed in terms of E_a versus magnetomotive force im amps, is given by the following table (to use this "curve", please use linear interpolation). Armature reaction is negligible in this machine. Neglect rotational losses.

Figure:

E_a (V)	95	150	188	212	229	243
MMF_f (A)	500	1,000	1,500	2,000	2,500	3,000

With the motor loaded so that its current is half the rated armature current, compute its torque and speed

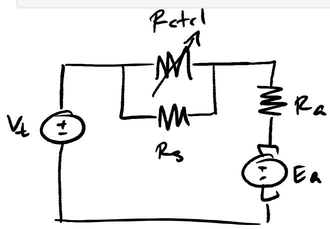
(a) $T_{50\%}$ = ______ $N.m$

(b) $n_{50\%}$ = ______ rpm

Now repeat the problem but with the motor draining full rated current

(c) $T_{100\%}$ = ______ $N.m$

(d) $n_{100\%}$ = ______ rpm



$V_t = 236V$
$N_s = 37$
$R_a = 0.03$
$R_s = 0.02$
$R_{ctrl} = \infty$

$I_t = I_a \qquad E_a = V_t - (R_s + R_a) I_a$

@ $I_t = \frac{1}{2} 61 \rightarrow E_a^n = 234.5V$

$MMF = N_s I_s \rightarrow MMF = 37(\frac{1}{2}61) = 1129A$

↳ from graph interpolation $\quad E_a^{900} = 159.8V$

$$n = \frac{900 \cdot E_a^n}{E_a^{900}} \rightarrow \boxed{n = 1321\ RPM}$$

$$\tau = \frac{E_a^n I_a}{n \frac{2\pi}{60}} \rightarrow \boxed{\tau = 51.7\ Nm}$$

@ $I_t = 61 \rightarrow E_a^n = 233V$

$MMF = 2257 \rightarrow E_a^{900} = 220.7V$

$$n = \frac{900(233)}{220.7} = \boxed{950.2\ RPM}$$

$$\tau = \frac{233(61)}{950.2 \frac{2\pi}{60}} = \boxed{142.8\ Nm}$$

(10 pts)
For the DC motor in the figure below, draw (these drawings may be asked in an exam, but are not for you to submit as part of this assignment; however, keep reading) an external DC power supply of 275 Vdc feeding this motor that has been connected (a) as a simple shunt motor with a field "adjustable" resistor of 100 ohms, no compensation winding; (b) as a series motor with a "controlling" resistor of 0.12 ohms (the one in parallel with the series coil), no compensation windings; (c) as a cumulative compounded long connection DC motor without compensation winding and a shunt field coil adjustable resistor of 100 ohms; (d) as a differential compounded short connection DC motor with compensation windings and a shunt field coil adjustable resistor of 100 ohms.

For every part above, produce three diagrams: a circuit diagram like the ones we used to solve numerical problems; a global view connection diagram (which in nothing but Figure 1 with the wires, adjustable resistor and external power supply); and a true wiring diagram (with the connection box on the right representing the actual motor, with the wires, adjustable resistor and external power supply).

If we know that Nf= 2100 turns per pole, Ns=23 turns per pole, Rf=178 ohms, Rs=0.03 ohms, Ra=0.26 ohms, Rcmp=0.027 ohms (compensation winding resistance), MMF_{AR} = 1360 A when Ia=78 A. The magnetization characteristic of this motor, measured at 1200 rpm, as Ea(V) as a function of I_f^* (A) is shown below. The current taken by the motor from the external source is 37 A. For each part above, what are the RPM and output torque. If the rotational losses are negligible. Note: In a short compound, the field coild circuit (R_{adj} plus R_f) are connected directly to the armature terminals!.

The DC machine and its connection box:

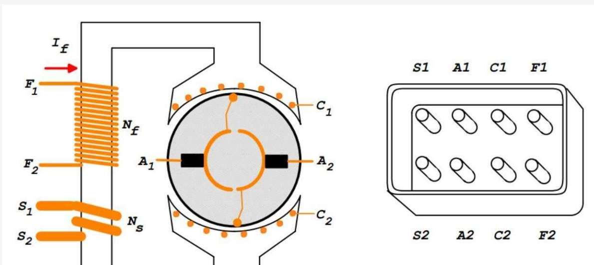
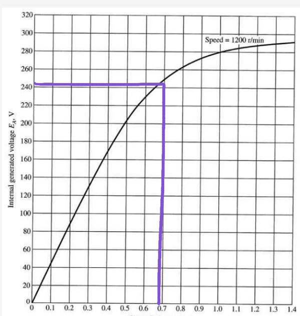


Figure 1

Magnetization characteristic $E_a = f(I_f^*)$:



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(a) For the shunt motor:

n = RPM and Torque = N.m

(b) For the series motor:

n = RPM and Torque = N.m

(c) For the cumulative compounded motor:

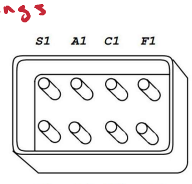
n = RPM and Torque = N.m

(d) For the differential compounded motor:

n = RPM and Torque = N.m

MMF = 1360A $I_{ar} = 78A$
$V_t = 275V$ $I_t = 37A$ $P_{rot} = \phi$
$R_f = 178$ $R_s = 0.03$ $R_a = 0.26$ $R_{cmp} = 0.027$
$N_f = 2100$ $N_s = 23$

SHUNT $R_{adj} = 100$ no compen windings



$$I_f = \frac{275}{100+178} = 989mA$$

$$I_f^* = I_f - \frac{\frac{1360}{78}}{2100} I_a = 690mA$$

$$\hookrightarrow E_a^{1200} = 247.9V$$

$I_a = 37 - I_f = 36.01A$

$E_a^n = 275 - I_a(R_a) = 265.6V$

$$n = \frac{1200(265.6)}{247.9} = \boxed{1286RPM}$$

$$\tau = \frac{265.6(36.01)}{\frac{2\pi}{60}} = \boxed{71Nm}$$

SERIES $R_{ctrl} = 0.12$ no compen. windings

$I_a = I_t = 37A$

$R_{eq} = (R_{ctrl} \,//\, R_s) + R_a = 0.284\Omega$

$E_a^n = 275 - 37R_{eq} = 264.5V$

$$I_s = \frac{I_a R_{ctrl}}{R_s + R_{ctrl}} = 29.6A$$

$$I_f^* = I_f + \frac{N_s}{N_f} I_s - \cancel{\frac{I_{AR}}{N_f}} I_a = 324.2mA$$

MMF ϕ

$\hookrightarrow E_a^{1200} = 138.5V$

$$n = \frac{1200 \cdot 264.5}{138.5} = \boxed{2292 RPM}$$

$$\tau = \frac{264.5(37)}{2292\frac{2\pi}{60}} = \boxed{40.78Nm}$$

LONG COMPOUND $R_{adj} = 100$ $R_{ctrl} = 0.12$

no compensation winding

$$I_f = \frac{275}{100+178} = 989.2mA$$

$I_a = 36.01$ $I_s = I_a \dfrac{R_{ctrl}}{R_s + R_{ctrl}} = 28.81$

$R_{eq} = 0.317\Omega \rightarrow E_a^n = 263.6V$

$I_f^* = 1.006 \rightarrow E_a^{1200} = 280V$

$$n = \frac{1200 \cdot 263.6}{280V} = \boxed{1131 PM}$$

$\boxed{\tau = 80.24Nm}$

DIFFERENTIAL SHORT CMP

$R_{adj} = 100$, $R_{ctrl} = 0.12$ are comp. windings

$V_1 = V_t - I_t(R_{ctrl} \,//\, R_s)$?

$E_a = V_1 - I_a(R_a + R_{comp})$

$I_f = \dfrac{V_1}{R_{adj} + R_f}$ $I_a = I_t - I_f$

$V_f = 286.5$

$I_f = 1.013A$

$I_a = 35.99$

$E_a^n = 276.8V$

$$I_s = I_t \frac{R_{ctrl}}{R_a + R_{ctrl}} = 17.53\,A$$

w/o $I_f^* = 937.7\,mA \rightarrow E_a^{1200} = 276.4$

w/ $I_f^* = 669\,mA \rightarrow E_a^{1200} = 243.8$

$n = 1202$

$$n = \frac{1200\, E_a^n}{E_a^{1200}} = 1362\ RPM$$

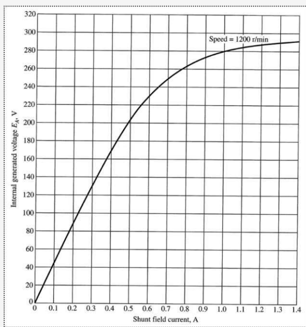
$(-) \nmid \phi$

$I_f^* = 878.2\,mA \rightarrow E_a^{1200} = 271.7$

$\rightarrow n = 1223$

(10 pts)
An independently excited DC motor whose armature is energized by an external DC source V_t that can range between 130 V and 210 V. Its field excitation circuit is independently energized by another DC voltage source V_f = 275 V. The field adjustable resistor R_{adj} can range between 76 Ω and 499 Ω. The resistance of the field coil is R_f = 116 Ω.

Magnetization characteristic $E_a = f(I_f)$:

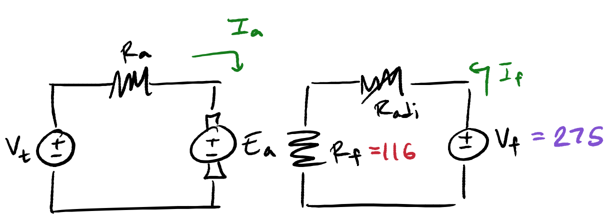


Field Current (A)	Ea (V) at 1200rpm
0	3.0305
0.4	170.2049
0.5	204.4685
0.6	230.4445
0.7	249.8647
0.8	263.966
0.9	273.8616
1	280.5412
1.1	285.1179
1.2	288.0247
1.3	290.2513
1.4	291.983

What is the maximum and minimum idling speed that this motor can attain by varying V_t and R_{adj} ...

(a) n_{max} = RPM

(b) n_{min} = RPM



$R_{adj} = 76 \rightarrow 499\,\Omega$ $\qquad I_f = \dfrac{V_f}{R_f + R_{adj}}$

@ $R_{adj} = 76\,\Omega$ $\quad I_f = 1.4323\,A$ $\quad E_a^{1200} = 291.983\,V$

@ $R_{adj} = 499\,\Omega$ $\quad I_f = 447.15\,mA$ $\quad E_a^{1200} = 187.15\,V$

assuming $I_a = \emptyset$, $V_t = E_a^n$

$V_t = 130 \rightarrow 210\,V$

$\frac{E_a^n}{1200}$ $\quad \rightarrow n = 1200 \dfrac{E_a^n}{E_a^{1200}}$

$\frac{E_a^n}{1200} \longrightarrow n = 1200 \frac{E_a^n}{E_a^{1200}}$

76Ω	130V	$n = 1200 \frac{130}{291.983} = \boxed{534.277}$
76Ω	210V	$n = 1200 \frac{210}{291.983} = 863.0659$
499Ω	130V	$n = 1200 \, {}^{130}/_{187.15} = 833.5559$
499Ω	210V	$n = 1200 \, {}^{210}/_{187.15} = \boxed{1346.5135}$