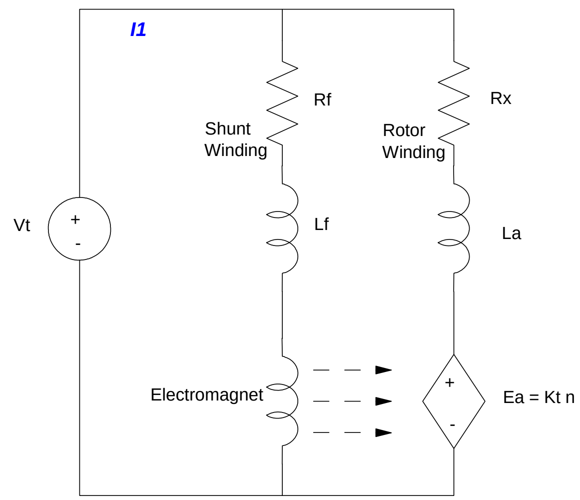
ECE 331 - Soulution to Homework #8

DC Shunt Excited Motors:

1) Assume a DC motor with Vt = 120VDC, Rf = 150 Ohms, Rx = 3 Ohm, Nf = 30, Na = 30, and a reluctance of 1000. Plot the speed vs. load torque relationship.



First, compute the torque constant:

$$I_f = \frac{120V}{150\Omega} = 0.8A$$

$$\Phi_P = \frac{N_f I_f}{Rel} = \frac{(30)(0.8)}{1000} = 0.024Wb$$

$$K_t = \frac{2N_a\Phi_P}{\pi} = 0.4584\frac{V}{\text{rad/sec}}$$

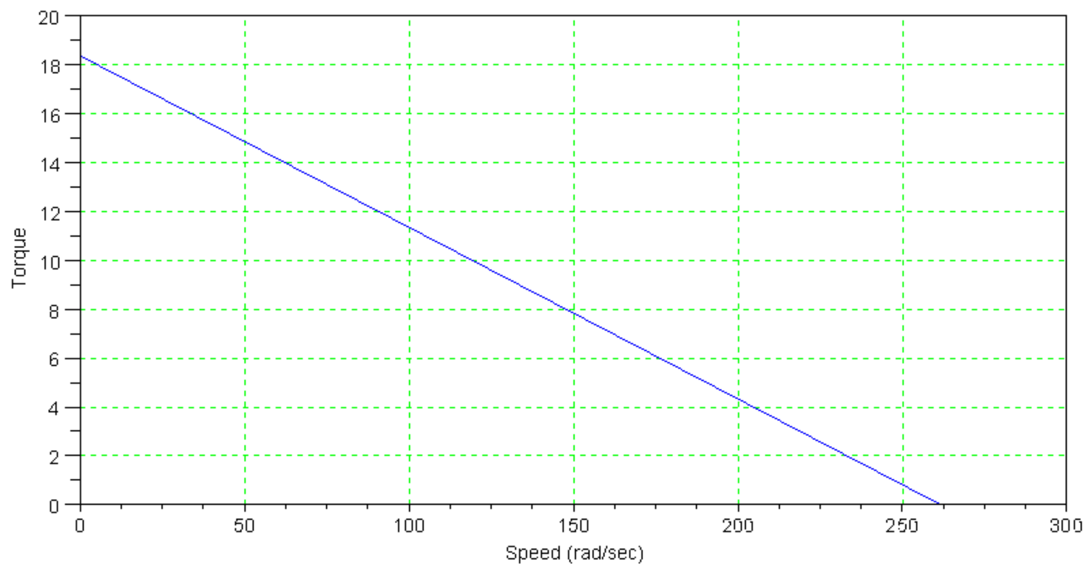
The speed vs. load relationship is then...

$$E_a = K_t\omega$$

$$I_a = \frac{120V - E_a}{R_x}$$

$$T = K_t I_a$$

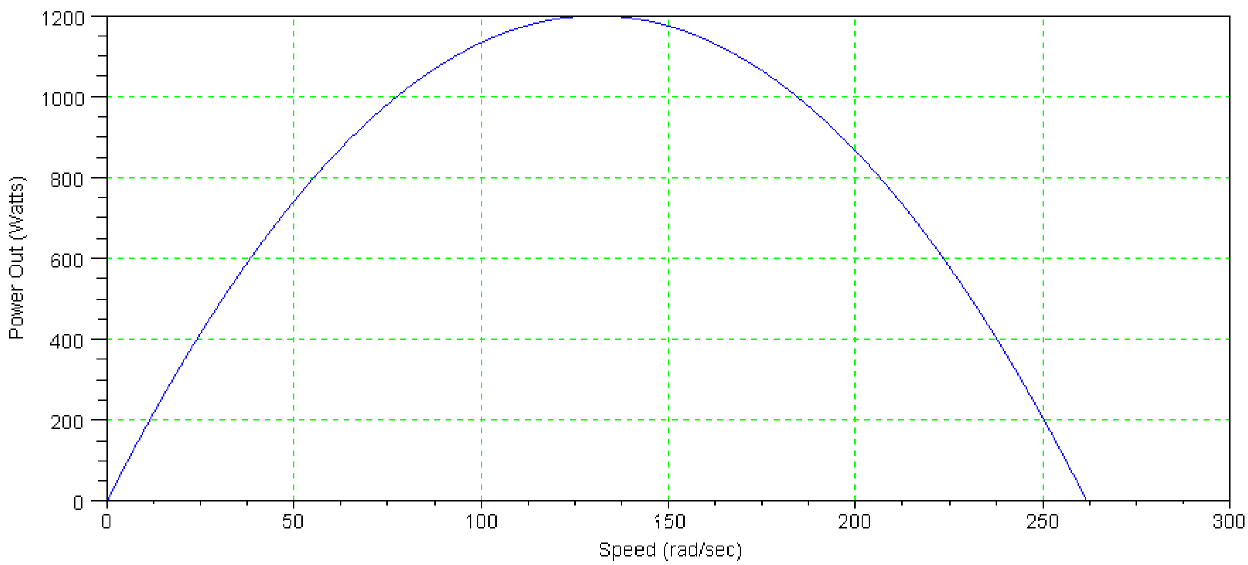
```
Vt = 120;
Rf = 150;
Rx = 3;
Kt = 0.4584;
Wmax = Vt / Kt


w = [0:0.01:1]' * Wmax;
Ea = Kt*w;
Ia = (Vt - Ea) / Rx;
T = Kt*Ia;
plot(w,T);
xlabel('Speed (rad/sec)')
ylabel('Torque');
xgrid(3)
```


Torque
Speed (rad/sec)
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
300

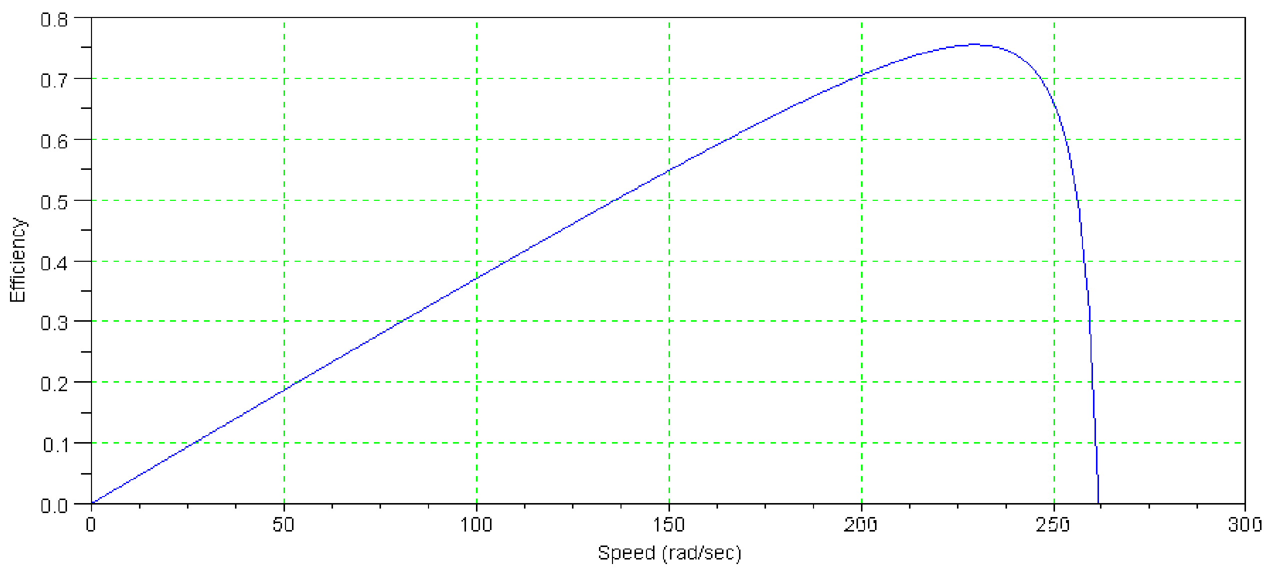
2) For the motor in problem #1, plot

- Speed vs. power out
- Speed vs. efficiency

```
-->Po = Ea .* Ia;
-->plot(w,Po);
-->xlabel('Speed (rad/sec)')
-->ylabel('Power Out (Watts)')
-->xgrid(3)
```



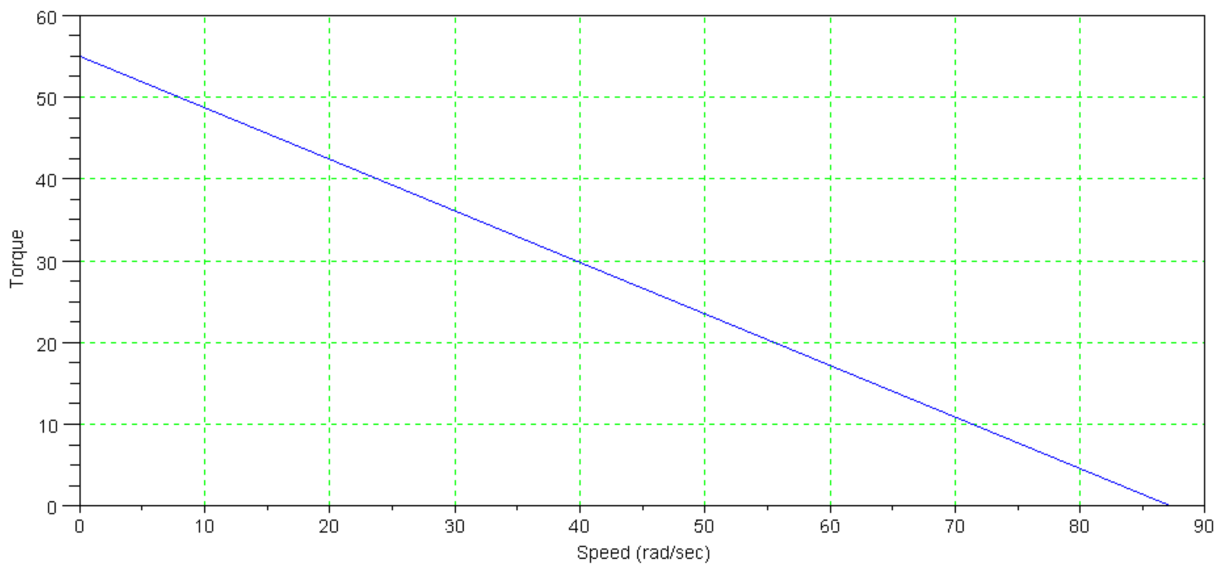

```
plot(w,(Ea.*Ia) ./ (Vt*(Ia + If)))
xgrid(3)
xlabel('Speed (rad/sec)')
ylabel('Efficiency')
```



3) Increase the field current by 3x (reduce Rf to 50 Ohms). Plot

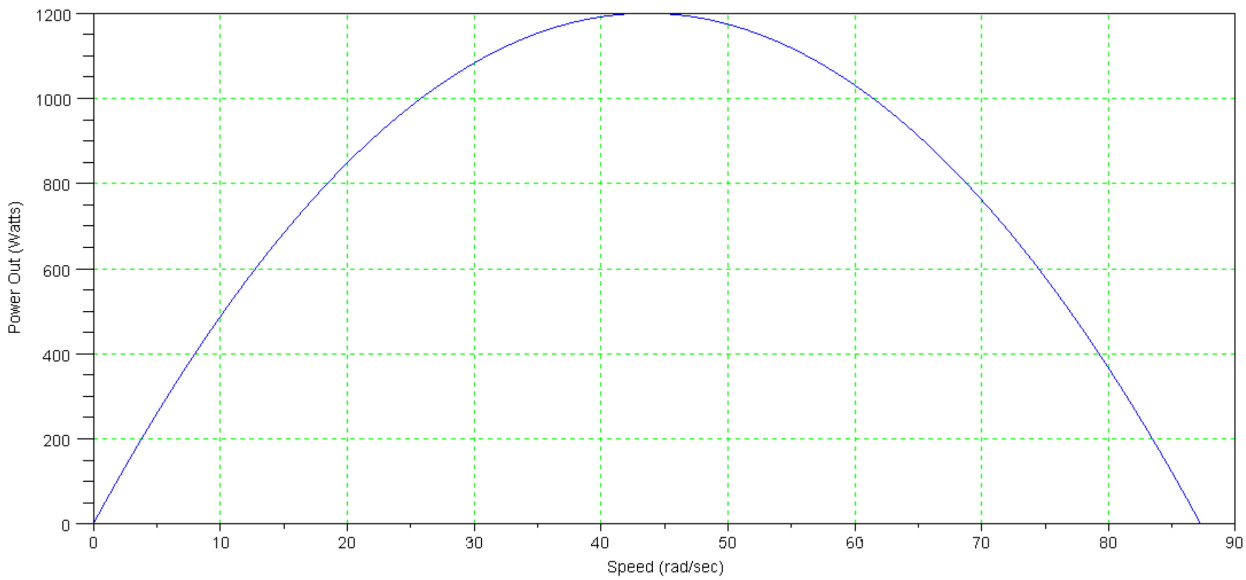
- Load torque vs. speed

```
Vt = 120;
Rf = 200;
Rx = 2;
Kt = 0.4297 * 3;
Wmax = Vt / Kt;
w = [0:0.01:1]' * Wmax;
Ea = Kt*w;
Ia = (Vt - Ea) / Rx;
T = Kt*Ia;
plot(w,T);
xlabel('Speed (rad/sec)')
ylabel('Torque');
xgrid(3)
```



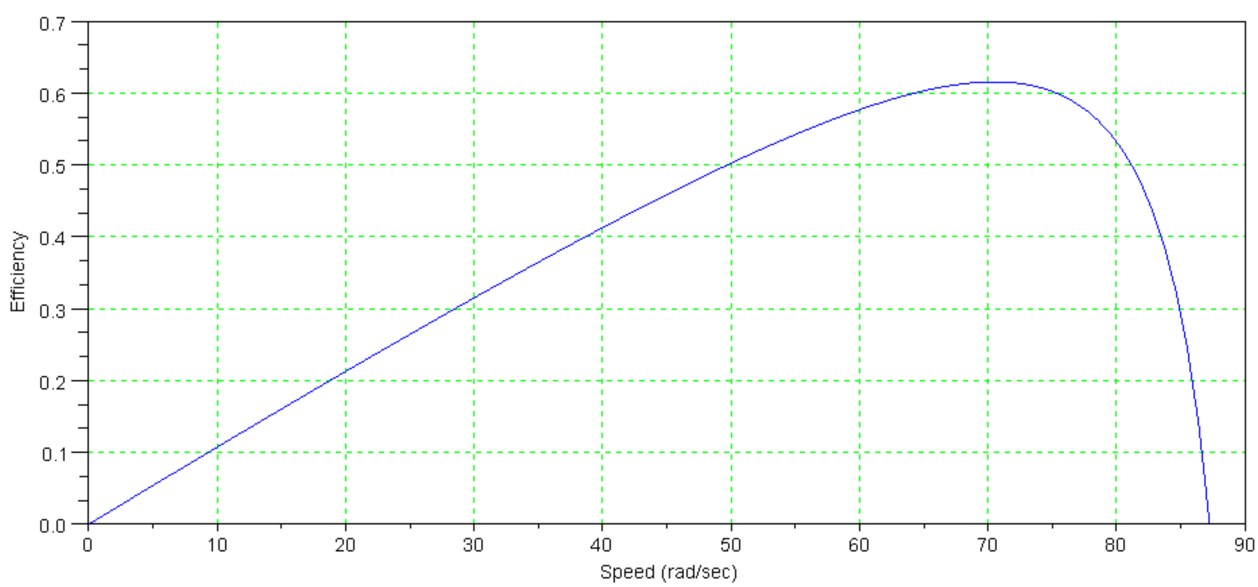
- Speed vs. power out

```
-->Po = Ea .* Ia;
-->plot(w,Po);
```



- Speed vs. efficiency

```
-->Pin = Vt*(Ia + If);
-->Eff = Po ./ (Pin + 0.00001);
-->plot(w,Eff)
-->xlabel('Speed (rad/sec)')
-->xgrid(3)
-->ylabel('Efficiency')
```



4) Design a DC shunt excited motor. The motor is to produce 15kW with Vt = 120VDC at 3000 rpm. Specify Rf, Rx, Kt.

```
4)  Design a DC shunt excited motor.  The motor is to produce 10kW with Vt = 120VDC
at 3600 rpm.  Specify Rf, Rx, Kt.
```

note: your designs will vary quite a bit.

One approach:

Assume your target is 85% efficient at the operating condition. Ignoring rotational losses, the efficiency is

$$0.85 = \frac{E_a}{V_t}$$

$$E_a = 102V$$

The torque constant is then

$$K_t = \frac{E_a}{\omega} = \frac{102V}{377 \text{ rad/sec}} = 0.271\frac{\text{V}}{\text{rad/sec}}$$

The torque is

$$T = \frac{P}{\omega} = \frac{15{,}000W}{377\text{rad/sec}} = 39.79Nm$$

The armature current

$$I_a = \frac{T}{K_t} = \frac{39.79Nm}{0.271\frac{Nm}{A}} = 146.8A$$

The armature resistance is

$$R_a = \frac{V_t - E_a}{I_a} = \frac{120V - 102V}{146.8A} = 0.1226\Omega$$

Let's use the same design as problem #1 with If adjusted. From problem #1,

- If = 0.8A produced Kt = 0.4584
- To reduce the torque constant to Kt = 0.271, redice If accordingly:

$$I_f = \left(\frac{0.271}{0.4584}\right)0.8A = 0.4729A$$

Find Rf to get this current:

$$R_f = \left(\frac{120V}{0.4729A}\right) = 253.7\Omega$$

Note: There are other ways to do this. Once you specify the efficiency, the other parameters drop out one by one.

If you specify efficiencies closer to 100%, the armature resistance gets closer to zero.

5) Determine the efficiency of the DC motor you designed for problem #4 at this operating condition.

$$P_o = 15,000W$$

$$P_{in} = (I_a + I_f)V_t$$

$$P_{in} = (146.8A + 0.4729A)120V$$

$$P_{in} = 17,672W$$

$$\eta = \frac{P_o}{P_{in}} = \frac{15{,}000W}{17{,}672W} = 84.8\%$$

Note: I designed for 85% efficiency. This is a little lower since the 85% computations did not include the field losses.

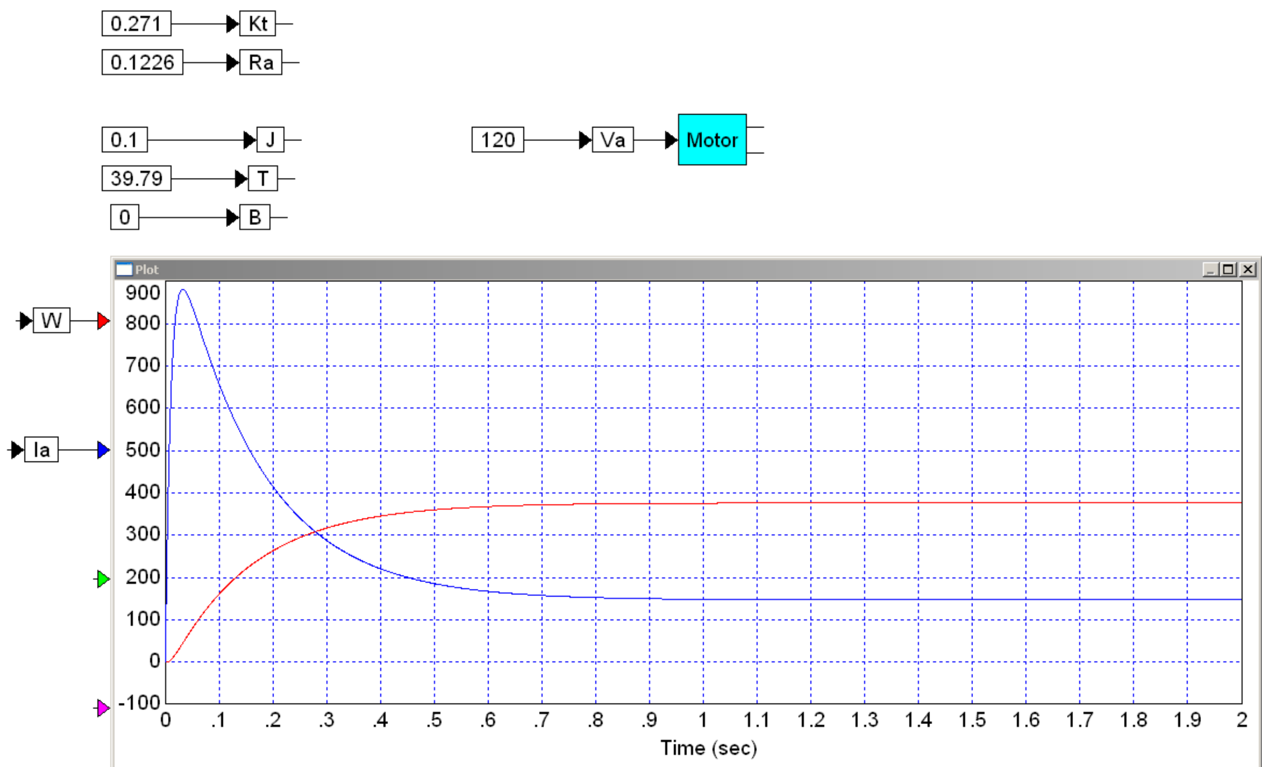
(MATLAB - numerical integration)

6) Assume the inertia of the DC motor is 0.1 kg m2 the the rotational losses are 1W/krpm.

Compute the speed vs. time using MATLAB as this motor accelerates from standstill to full speed.

Plot

- Speed vs. time
- Current vs. time



note: The in-rush current is about 6x the current requred to output 15kW. If your motor isn't designed for that much current, you might burn it out on start-up.