EE361 HW#1 FALL 2016

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NAME: *SOLUTION*

Q.1)

Given parameters

```
path_length = 145e-3; % m
core_area = 15.8e-6; % m^2
Bsat = 0.51; % Tesla
Lrequired = 220e-6; % H
relative_perm = 3000;
air_perm = 4*pi*1e-7; % H/m
```

Part I)

Import the nonlinear B-H data

```
BHdata = xlsread('B-H_char.xlsx');
Hnonlinear = BHdata(:,1);
Bnonlinear = BHdata(:,2);
```

Part A)

Calculate the number of turns

```
permeability = relative_perm*air_perm; % H/m
reluctance = path_length/(permeability*core_area);
turns = sqrt(reluctance*Lrequired);
turns = round(turns);
fprintf('Required number of turns is %d.\n',turns);
```

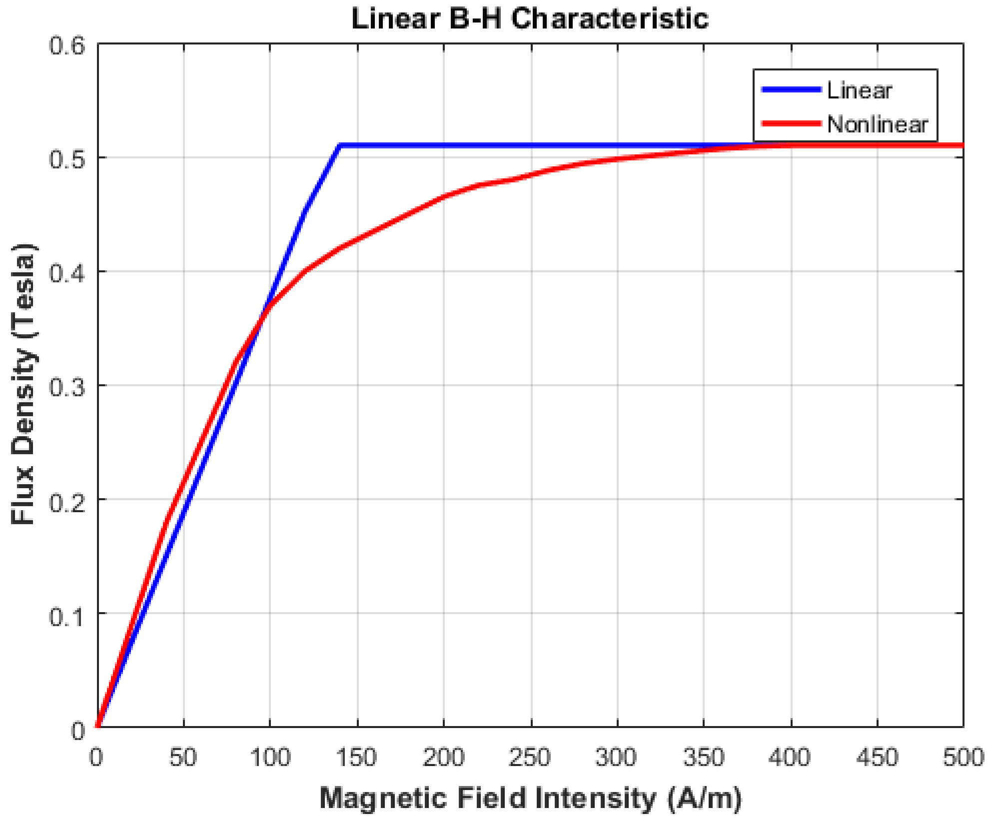
```
Required number of turns is 23.
```

Part B)

```
permeability = relative_perm*air_perm; % H/m
Hsat = Bsat/permeability; % A/m

Hlinear = 0:20:500; % A/m
Blinear = zeros(1,numel(Hlinear)); % Tesla
for k = 1:numel(Hlinear)
    if Hlinear(k)<=Hsat
        Blinear(k) = Hlinear(k)*permeability;
    else
        Blinear(k) = Bsat;
    end
end

figure;
plot(Hlinear,Blinear,'b-','LineWidth',2.0);
hold on;
plot(Hnonlinear,Bnonlinear,'r-','LineWidth',2.0);
hold off;
xlabel('Magnetic Field Intensity (A/m)','Fontweight','Bold');
ylabel('Flux Density (Tesla)','Fontweight','Bold');
title ('Linear B-H Characteristic','Fontweight','Bold');
legend('Linear','Nonlinear');
grid on;
```



Part C)

Linear case:

```
flux_density = 0.30;
current_linear = (flux_density*path_length)/(permeability*turns);
fprintf('The required inductor current for linear case is %d Amps.
\n',current_linear);
```

The required inductor current for linear case is 5.016841e-01 Amps.

Nonlinear case:

```
Hrequired = 75; % A/m
current_nonlinear = (Hrequired*path_length)/(turns);
fprintf('The required inductor current for nonlinear case is %d Amps.
\n',current_nonlinear);
```

The required inductor current for nonlinear case is 4.728261e-01 Amps.

Part D)

Linear case:

```
flux_density = 0.45;
```

```
current_linear = (flux_density*path_length)/(permeability*turns);
fprintf('The required inductor current for linear case is %d Amps.
\n',current_linear);

% Nonlinear case:

Hrequired = 180; % A/m
current_nonlinear = (Hrequired*path_length)/(turns);
fprintf('The required inductor current for nonlinear case is %d Amps.
\n',current_nonlinear);
```

```
The required inductor current for linear case is 7.525261e-01 Amps.
The required inductor current for nonlinear case is 1.134783e+00 Amps.
```

As it can be observed from the B-H curves for linear and nonlinear cases, the operating points are very close for 0.3 Tesla whereas there is a larger deviation for 0.45 Tesla. This result shows that linear approximation is a good practice and can estimate in the vicinity of the operating point; however, the estimation may fail when the inductor operates at a different point.

Part II)

```
Imax = (Bsat*path_length)/(permeability*turns);
fprintf('The maximum current without saturating the core is %d Amps.
\n',Imax);
```

```
The maximum current without saturating the core is 8.528629e-01 Amps.
```

Part III)

```
stored_energy = (1/2)*Lrequired*Imax^2; % Joules
fprintf('Stored energy with this current is %d Joules.
\n',stored_energy);

core_volume = core_area*path_length; % m^3
stored_energy2 = (Bsat^2/(2*permeability))*core_volume;
fprintf('Stored energy found with B-H point is %d Joules.
\n',stored_energy2);
```

```
Stored energy with this current is 8.001126e-05 Joules.
Stored energy found with B-H point is 7.903225e-05 Joules.
```

energy stored on an inductor can be calculated by using both electrical parameters and magnetic parameters. Calculation with electrical parameters is usually performed for the selection of the core using the design specifications (required inductance and maximum current). Calculation with magnetic parameters is more useful when hysteresis losses are to be calculated or core material is to be selected.

Part IV)

One may insert an air gap to the core. Air has a relative permeability of 1 so that, even a small air gap will result in a large reluctance. If the same inductance is to be achieved, reqired number of turns will increase. For the same flux (and flux density, note that area is not changing), a larger reluctance will yield a higher current at saturation point. Therefore, more energy can be stored if inductance is the same.

Part V)

As the core saturates; the relative permeability of the core will drop because flux density cannot be made larger with a higher magnetic field intensity. The reluctance of the core will increase since the relative permeability decreases. Inductance will decrease since the reluctance increases. An inductor, thus, cannot be considered to have a constant inductance at all times. Depending on the application, if the design is not well enough such that some of the operation lies in the saturation region, inductance will be variable.

Q.2)

Given parameters

```
gap_length = 1e-2; % m
Bsat = 1; % Tesla
Hsat = 300; % A/m
core_area = 10e-4; % m^2
air_perm = 4*pi*1e-7; % H/m
turn = 30;
```

Part I)

```
permeability = Bsat/Hsat; % H/m
relative_perm = permeability/air_perm;
fprintf('Relative permeability of the core is %d.\n',relative_perm);
```

Relative permeability of the core is 2.652582e+03.

Part II)

```
BlegB = 0.9; % Tesla
length_B = 0.3; % m
length_C = 0.09; % m
reluctance_B = length_B/(permeability*core_area);
reluctance_C = length_C/(permeability*core_area)+gap_length/
(air_perm*core_area);
reluctance_A = reluctance_B;
flux_B = BlegB*core_area; % Weber
flux_C = flux_B*(reluctance_B/reluctance_C);
flux_A = flux_B+flux_C;
MMF = flux_A*reluctance_A+flux_C*reluctance_C;
current = MMF/turn;
fprintf('Coil-A current is %d Amps.\n',current);
```

Coil-A current is 5.430433e+00 Amps.

Part III)

```
flux_density_gap = flux_C/core_area;
fprintf('The flux density in the gap is %d Tesla.
\n',flux_density_gap);
```

```
The flux density in the gap is 1.014434e-02 Tesla.
```

Part IV)

If one applies superposition, it will be seen that flux due to coil-A is cancelled by flux due to coil-B in the air gap. Therefore, flux density in the air gap will be zero. Moreover, flux due to coil A only is the same as the one found in part II in leg-B. Flux created in leg-B due to coil-B will be the same (in magnitude) flux created in leg-A due to coil-A, which was found also in part II. As they will have the same direction because of the current directions in the coils, total flux in leg-B can be found as follows:

```
flux_B_duetoA = flux_B;
flux_B_duetoB = flux_A;
flux_B = flux_B_duetoA + flux_B_duetoB;
flux_density_B = flux_B/core_area;
```

Then again, the core will be saturated, so flux density will be 1 Tesla (Bsat).

```
flux_density_gap = 0;
flux_density_B = 1;

fprintf('The flux density in the gap is %d Tesla.
\n',flux_density_gap);
fprintf('The flux density in leg-B is %d Tesla.\n',flux_density_B);
```

```
The flux density in the gap is 0 Tesla.
The flux density in leg-B is 1 Tesla.
```

Part V)

When the current is doubled, it is obvious that leg-A which has the highest flux will be saturated. Therefore, its flux density will be 1 Tesla (Bsat).

```
flux_density_A = 1;
flux_A = flux_density_A * core_area;
flux_C = flux_A/(1+reluctance_C/reluctance_B);
flux_B = flux_A/(1+reluctance_B/reluctance_C);
flux_density_gap = flux_C/core_area;
flux_density_B = flux_B/core_area;

fprintf('The flux density in the gap is %d Tesla.
\n',flux_density_gap);
fprintf('The flux density in leg-B is %d Tesla.\n',flux_density_B);
```

```
The flux density in the gap is 1.114586e-02 Tesla.
The flux density in leg-B is 9.888541e-01 Tesla.
```

Part VI)

A DC excitation will result in a constant magnetic field on the core. In order to dissipate power on the resistor, current should be induced which can be achieved by inducing voltage on coil-B. It is not possible to induce voltage on coil-B with constant magnetic field since e = Ndphi/dt.

Part VII)

With sinusoidal excitation, a time-varying magnetic field is created so that voltage can be induced on coil-B. The induced voltage will result in a current on the resistor so that power can be dissipated. Actually, this is how a transformer works.

PArt VIII)

Since the excitation is doubled, the core will saturate as the previous flux density was close to the saturation point. Therefore, the current on the resistor will not increase proportionally.

Part IX)

Removal of the gap will result in reduction on the reluctance of the center leg (where the gap was present). Therefore, more flux will flow through the center leg as its reluctance decreased so that the mutual inductance will decrease.

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