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# Question 1

## Part A

In this part I made all calculations with MATLAB so I have used MATLAB report generator.

### Part A.1

% In this part, magnetic flux is assumed homogeneously, and use effective  
% length from datasheet.  
  
  
u0 = 4\*pi\*10^-7;  
  
core\_Al = 5040; % nH/turn^2  
core\_le = 103e-3; % m eff length  
core\_Ae = 138e-6; %m^2 cross sec area  
core\_height = 18e-3;  
  
core\_inner\_r = 13.1e-3;  
core\_outer\_r = 20.9e-3;  
  
  
core\_init\_ur = 3000; %initial ur  
  
core\_ur = 4500; % @ 425mT  
  
B\_op = 0.425;  
  
N = 20;  
Imax = B\_op\*core\_le/(core\_ur\*u0\*N);  
  
I = 0.43;  
  
core\_R = core\_le/(core\_ur\*u0\*core\_Ae); %reluctance  
  
core\_L = N^2/core\_R %H

core\_L =

0.0030

### Part A.2

% L = N\*fi/I , fi = NI/R, L = N^2(1/R1+1/R2...)  
  
% in order to modeled this I have calculated 10 different reluctance  
% which is effected flux and inductance then calculated inductance  
  
% inner parts of the toroid has small effective length this cause smaller  
% reluctance so that magnetic flux density and magnetic flux is high at  
% smaller radius and smaller higher radius. Also our assumption of the  
% first part is verified.  
  
core\_r\_div = linspace(core\_inner\_r,core\_outer\_r, 11);  
  
core\_r\_div\_effective = zeros(10,0);  
core\_R\_div\_effective = zeros(10,0);  
core\_le\_div\_effective = zeros(10,0);  
core\_Ae\_div = zeros(10,0);  
core\_L\_div = zeros(10,0);  
core\_flux\_div = zeros(10,0);  
total\_div\_flux = 0;  
total\_div\_inductance = 0;  
  
for i = 1:10  
  
 core\_r\_div\_effective(i) = (core\_r\_div(i) + core\_r\_div(i+1))/2;  
  
 core\_le\_div\_effective(i) = 2\*pi\*core\_r\_div\_effective(i);  
  
 core\_R\_div\_effective(i) = core\_le\_div\_effective(i)/(core\_ur\*u0\*core\_Ae/10);  
  
 core\_L\_div(i) = N^2 / core\_R\_div\_effective(i);  
  
 core\_flux\_div(i) = N\*I/core\_R\_div\_effective(i);  
  
 total\_div\_inductance = total\_div\_inductance + core\_L\_div(i);  
 total\_div\_flux = total\_div\_flux + core\_flux\_div(i);  
  
end  
  
  
plot(core\_r\_div\_effective,core\_L\_div);  
title('inductance vs radius part 1');  
xlabel('radius');  
ylabel('inductance');  
  
figure;  
  
plot(core\_r\_div\_effective,core\_flux\_div);  
title('flux vs radius part 1');  
xlabel('radius');  
ylabel('flux');  
  
figure;  
  
total\_div\_flux  
  
total\_div\_inductance

total\_div\_flux =  
 6.3957e-05  
  
total\_div\_inductance =  
  
 0.0030

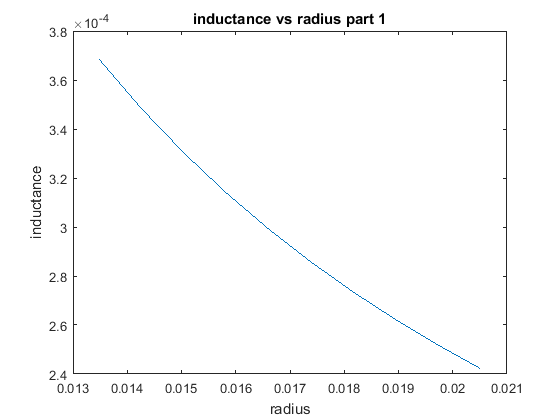


Figure 1

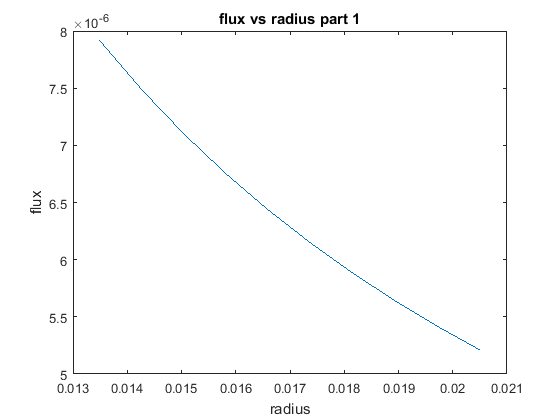


Figure 2

### Part A.3

% In this part magnetic flux density is saturated so that increasing  
% current cause to decrease permeability so that inductance of the inductor  
% decrease also, same as part 3 magnetic flux and flux density higher  
% at the smaller radius of the core because of smaller effective distance  
% and reluctance.  
  
  
% NI = B\*A\*R  
core\_u\_part3 = 0;  
I\_part3 =0;  
core\_ur\_part3 = 0;  
  
I\_part3 = I\*1.5;  
  
core\_B\_sat = 0.53;  
  
core\_u\_part3 = (core\_B\_sat \* core\_le) /(N\*I\_part3);  
  
core\_ur\_part3 = core\_u\_part3 /(4\*pi\*10e-7)  
  
core\_R\_part3 = core\_le/(core\_ur\_part3\*u0\*core\_Ae); %reluctance  
  
  
core\_L\_part3 = N^2/core\_R\_part3 %H  
  
core\_flux\_part3 = N\*I\_part3/core\_R\_part3  
  
  
% part 3 division  
  
core\_R\_div\_effective\_part3 = zeros(10,0);  
core\_L\_div\_part3 = zeros(10,0);  
core\_flux\_div\_part3 =zeros(10,0);  
total\_inductance\_div\_part3 = 0;  
total\_flux\_div\_part3 = 0;  
  
for i = 1:10  
  
 core\_R\_div\_effective\_part3(i) = core\_le\_div\_effective(i)/(core\_ur\_part3\*u0\*core\_Ae/10);  
  
 core\_L\_div\_part3(i) = N^2 / core\_R\_div\_effective\_part3(i);  
  
 core\_flux\_div\_part3(i) = N\*I\_part3/core\_R\_div\_effective\_part3(i);  
  
 total\_inductance\_div\_part3 = total\_inductance\_div\_part3 + core\_L\_div\_part3(i);  
 total\_flux\_div\_part3 = total\_flux\_div\_part3 + core\_flux\_div\_part3(i);  
  
end  
  
  
plot(core\_r\_div\_effective,core\_L\_div\_part3);  
title('inductance vs radius part 3');  
xlabel('radius');  
ylabel('inductance');  
  
figure;  
  
plot(core\_r\_div\_effective,core\_flux\_div\_part3);  
title('flux vs radius part 3');  
xlabel('radius');  
ylabel('flux');  
  
figure;  
  
total\_flux\_div\_part3  
  
total\_inductance\_div\_part3

core\_ur\_part3 =  
  
 336.7546  
  
  
core\_L\_part3 =  
  
 2.2679e-04  
  
  
core\_flux\_part3 =  
  
 7.3140e-06  
  
  
total\_flux\_div\_part3 =  
  
 7.1792e-06  
  
  
total\_inductance\_div\_part3 =  
  
 2.2261e-04

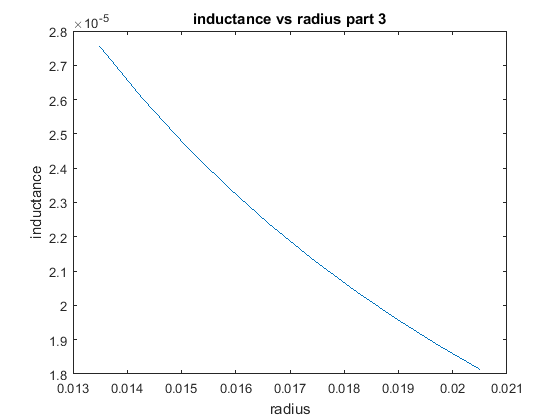


Figure 3

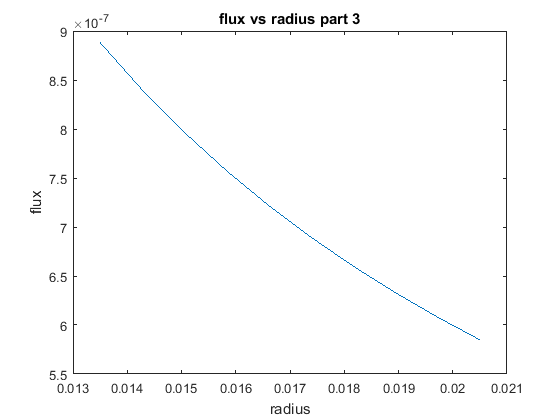


Figure 4

### Part A.4

% By adding gap to core increase the reluctance so decrease the inductance and  
% core flux. Fringing flux is neglected.  
  
d\_gap = 2e-3;  
  
core\_le\_part4 = core\_le - 2e-3;  
  
gap\_R = d\_gap/(core\_Ae\*u0);  
  
core\_R\_part4 = core\_le\_part4/(core\_ur\*u0\*core\_Ae); %reluctance  
  
core\_L\_part4 = N^2/(core\_R\_part4+gap\_R) %H

core\_L\_part4 =  
  
 3.4298e-05

### Part A.5

% In this part, in order to model fringing flux I increase the air gap a  
% little, in order to decide this distance I found required reluctance to model  
% fringing distance. Also, ı have used this reluctance to calculate  
% inductance  
%  
% Formula of fringing flux is 1+(d\_gap/sqrt(Acore))\*ln(2\*window\_area/d\_gap)  
%  
  
area\_window= 2\*pi\*core\_inner\_r;  
  
fringing\_flux = 1+(d\_gap/sqrt(core\_Ae))\* log(2\*area\_window/d\_gap);  
  
d\_fringing = N\*I\*core\_Ae\*u0/fringing\_flux  
  
fringing\_R = d\_fringing/(core\_Ae\*u0);  
  
core\_L\_part5 = N^2/(core\_R\_part4+gap\_R+fringing\_R) %H  
  
% By using this formula, d\_fringing is came so small, so that effect of fringing  
% could not seen obviously

d\_fringing =  
 8.5178e-10

core\_L\_part5 =  
 3.4298e-05

## Part B

### Part B.1

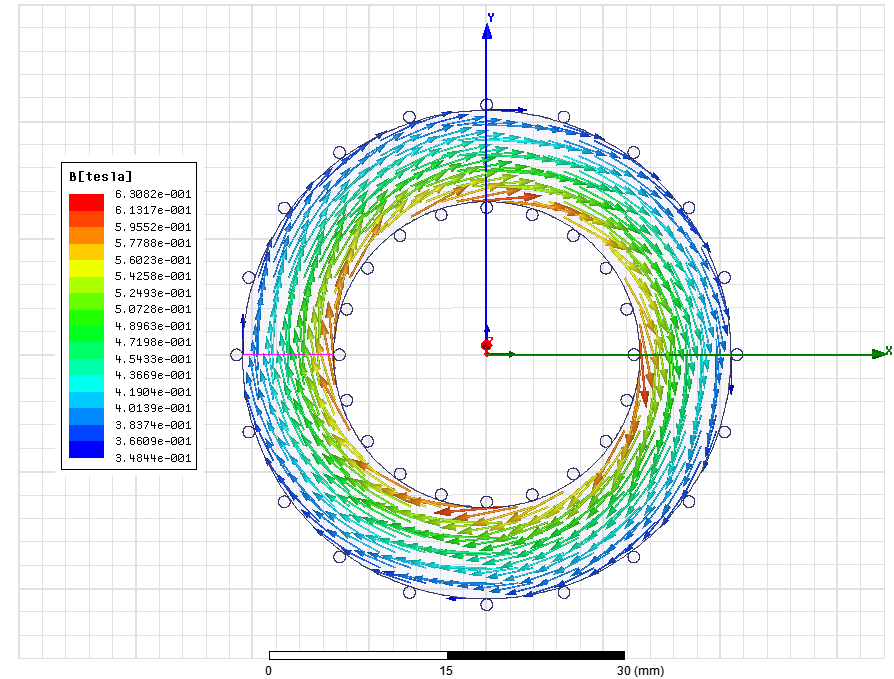


Figure 5

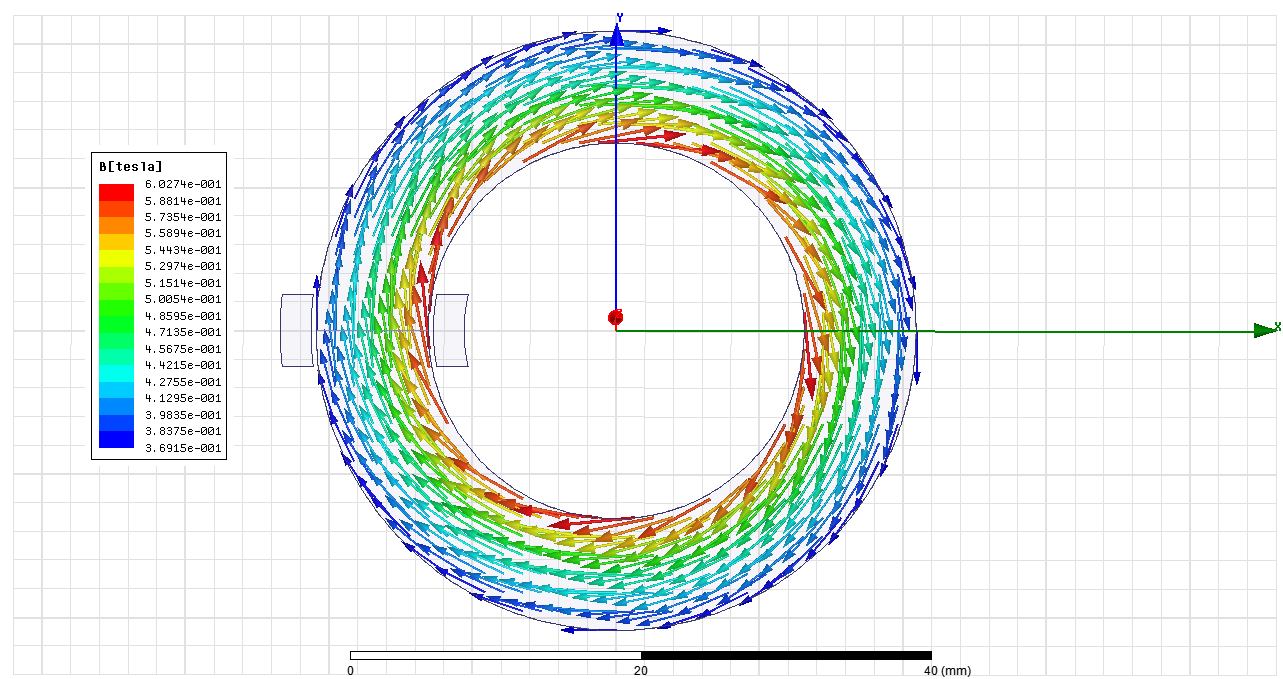


Figure 6

### Part B.2

Stored energy of the core is calculated from magnetic flux passing on L1 and leakages are modeled with L2 and L3 line fluxes.

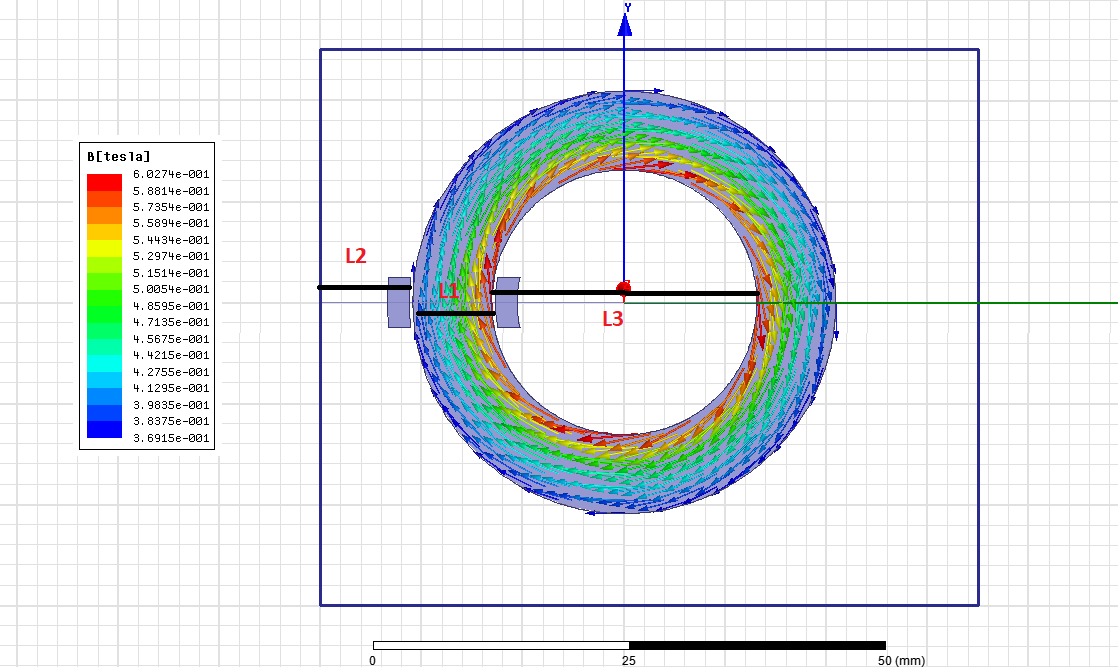


Figure 7

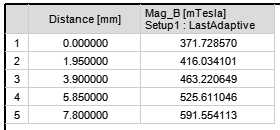


Figure 8. Magnitute of magnetic flux density on L1

From figure 8, average magnetic flux density on the core is calculated as 473.2 mT. Then with following formula reluctance is calculated. (N = 20, I = 0.435A, B = 0.473.2T, A = 138mm^2)

Reluctance is found as R = 133.22 \* 10^3, then with following formula, total inductance is **3mH** as founded analytically.

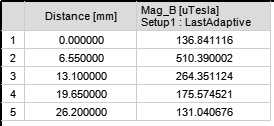
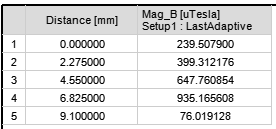


Figure . Magnitute of magnetic flux density on L2(left) and L3(right)

Avarege magnetic flux density on L2 is 459uT and on L3 is 243uT, then total leakage magnetic flux density is 702uT.

# Question 2

There is a lot of trade offs when designing transformer so that optimization of design really important. All important parameters are explained bottom.

|  |  |
| --- | --- |
| Power, Vin,Vo, Freq, temp, Iin, Iout | These parameters depend on customer needs, main purpose is designer obtaining these needs with maximum efficiency with minimum cost |
| Temperature | It effects B-H curve directly, so it is important for calculation |
| Type (square, E, C core) | Calculation of magnetic circuit depends on shape |
| Lamination type | According to frequency and material, eddy current and core loss decrease with lamination |
| B,H | Main operating flux density is decided according to material B-H curve |
| Cable resistivity, radius etc | According to current of transformer, cable is chosen then these parameters obtained |
| Core cross section | Cross section area effects reluctance, flux, inductance of the transformer, these parameters are so critically for magnetic circuits and also size and core loss of the transformer, it should be optimized |
| N1, N2 | These parameters also effects flux, inductance etc. Choosing this value high leads to high copper loss, choosing low leads to low flux and high core size |
| Window size | This value is decided according to fill factor, winding height and also cable quantity of the winding cable |
| Power factor | It is needed for efficiency calculation |

**Table 1. Important Input Parameters of Transformer Design**

## Reference

%http://www.encyclopedia-magnetica.com/doku.php/flux\_fringing