Chad Meadowcroft
2016

EIEN20 Assignment 1

Introduction

The aim of this assignment was to test and analyse two different simulation methods for a shell type transformer with varying geometrical proportions. We used Matlab to simulate an equivalent circuit for the transformer (ECM), and FEMM for a finite element representation of the transformer (FEM).

The main questions and objectives for this assignment:

1.) Which geometrical proportions allow the transformer to transfer the most power and which allow the highest efficiency?
2.) What are the differences between the two simulation method's results and why?
3.) General interpretation of results.
4.) What is the relationship between 'ks' (the proportion between Electric and Magnetic circuits) and current density, transferred power and copper and core losses?
5.) Compare data with real life example.

Geometry

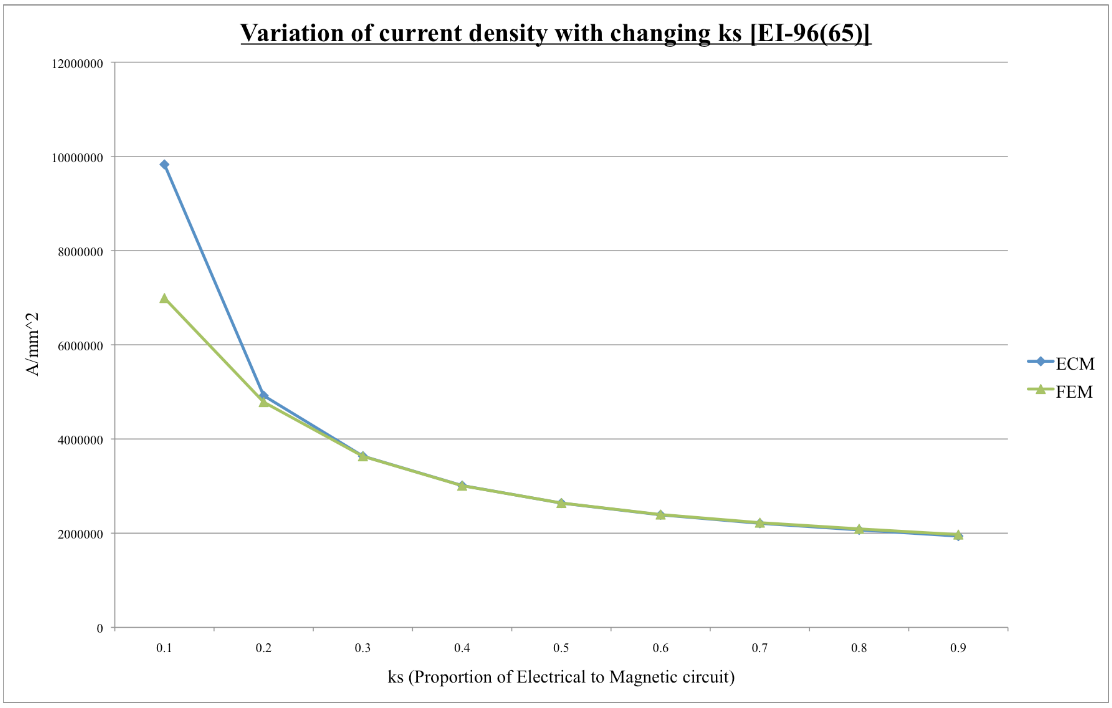
My first aim was to find the most efficient geometrical option for the transformer. I ran FEM and ECM simulations for the initial values (Height=0.05m, Length=0.1m, Width=0.08m) and recorded the data in excel for each value of ks (0.1-0.9). With this first simulation my main goal was to make sure the values from the different programs were similar. They were acting as expected so I ran simulations for the next set of sizes (EI-84). After this I ran the simulations for the largest sizes (EI-180).

Initially, the most noticeable results are that of pcu and jc1 for the large transformer EI-180. For low ks values (0.1-0.3) pcu is very small and jc1 is negative. I will attribute this to an overheating effect as the 'max coil temperature' in both simulations is set to 125 degrees. Overheating seems to occur in every suggested transformer except the smallest two.

I chose the following transformer for my analysis small enough to avoid the overheating problems of the large transformers but large enough to be semi-compared to a real TRAMO-ETV transformer.

Lamination type	*Length Ltr [mm]*	*Width Wtr [mm]*	*Stack Height Hc [mm]*
EI-96	*96*	*80*	*65*

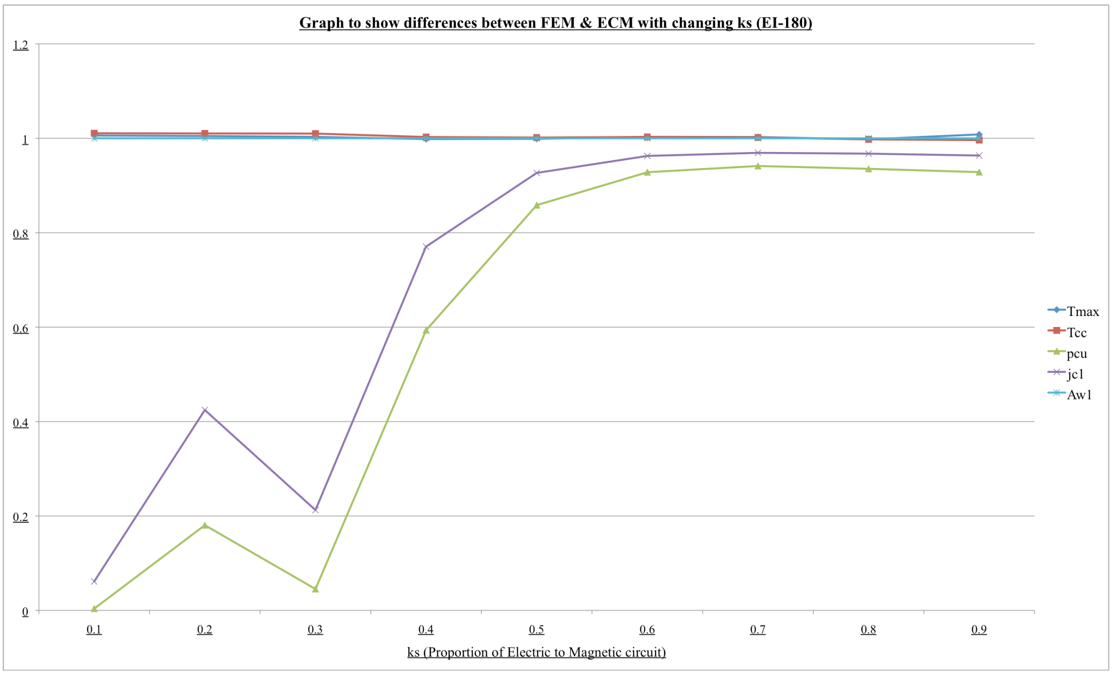
For this transformer I plotted the current density (jc1) for both simulation methods against the proportion of Electrical to Magnetic circuit area (ks).



We can note that the current density decreases with an increase in the proportion (more electrical) as would be expected. Also the difference in simulation methods can be seen, their results are more similar for higher proportions of Electrical circuit area.

Comparison of ECM & FEM

To exaggerate the small differences seen in the last simulations I changed to the EI-180 to examine the differences in results between the ECM and FEM results. The main differences in results come solely from the Current Density (jc1) and the Coil Losses (pcu). It's also clear that these differences are massively exaggerated only for low values of ks.



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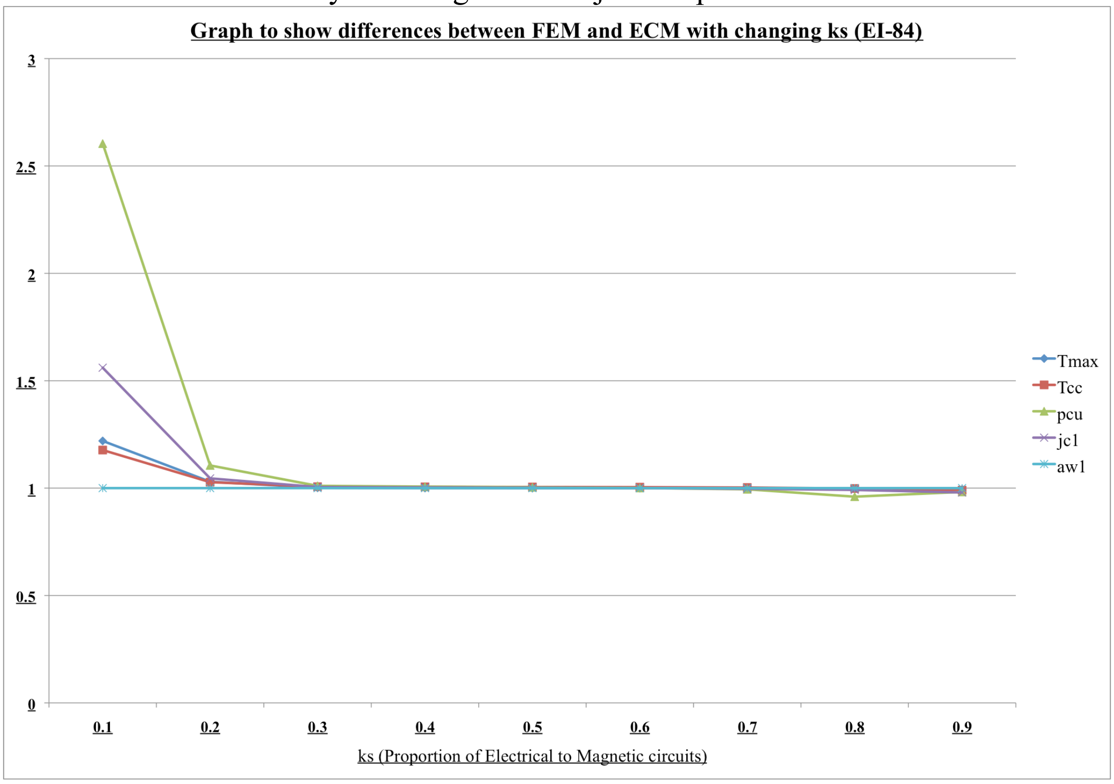
The strange effects on jc1 and pcu due to (supposed) overheating may be interfering with this secondary analysis, although the effects occur on both simulations. For this reason I decided to compare in the same way for EI-84 to determine whether the different simulations really did disagree about jc1 and pcu.



It is easy to observe that the differences are not so large but still present in this smaller transformer for low ks. When ks is low it means that there is a large amount of magnetic circuit to a relatively small electrical circuit so the difference we can see for pcu (coil losses) may be due to the difficulty of simulating a small electrical area.

<u>Power and Efficiency</u>

Here I'll show an example calculation of power flows and efficiency using ks=0.5. The values I will use for this section are as follows:

$$ks = 0.5$$
$$kf = 0.6$$
$$ins = 0.001m$$
$$\omega = 2\pi \cdot 50 rad/s$$
$$Jm = 2638652.59 A/m^2$$
$$B_m = 1.4T$$
$$\rho_e = 5335.4914 W/m^3$$

I had to calculate area of the magnetic and electric circuits:

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$$A_m = Hc \cdot lc = Hc \cdot 0.5 \cdot Ltr \cdot ks$$
$$A_m = 0.065 \cdot 0.5 \cdot 0.096 \cdot ks = 1560\,mm^2$$

$$A_e = lw1(Ws - 2ins) \cdot Kf = \left(\frac{Ltr}{2} \cdot ks\right) - 3ins) \cdot Kw \cdot \left(Wtr - \left(\frac{Ltr}{2} \cdot (1 - ks)\right) - 2ins\right) \cdot Kf$$
$$A_e = \left(\left(\frac{0.096}{2} \cdot 0.5\right) - 3 \cdot 0.001\right) \cdot 0.5 \cdot \left(0.08 - \left(\frac{0.096}{2} \cdot (1 - 0.5)\right) - 2 \cdot 0.001\right) \cdot 0.6$$
$$A_e = 340.2\,mm^2$$

I also calculated a rough length for the electric circuit, which doesn't account for the turns; this value will be higher than actual circuit length:

$$l_e = 2(hc + ls) + 6(ls)$$
$$l_e = 2(0.065 + 0.024) + 6(0.024)$$
$$l_e = 0.322\,m$$

Transferred Power:

$$P = \frac{1}{2}\omega B_m J_m A_e A_m = 0.5 \cdot 2\pi \cdot 50 \cdot 1.4 \cdot 2638652.9 \cdot 0.0003402 \cdot 0.0015$$
$$P = 307.94\,W$$

Losses:

$$p_{fe} = (2.5517 B_m^2 - 1.2936 B_m + 0.8143) \cdot 770$$
$$p_{fe} = 3083.36\,W$$
$$P_{fe} = p_{fe} A_m l_m = 3083.36 \cdot 0.00156 \cdot 0.065$$
$$P_{fe} = 3.127\,W/m^3$$

$$P_{cu} = \rho_e A_e l_e = 53354.91 \cdot 0.0003402 \cdot 0.322$$
$$P_{cu} = 5.845\,W/m^3$$

$$P_{loss} = P_{fe} + P_{cu} = 3.127 + 5.845$$
$$P_{loss} = 8.972\,W/m^3$$

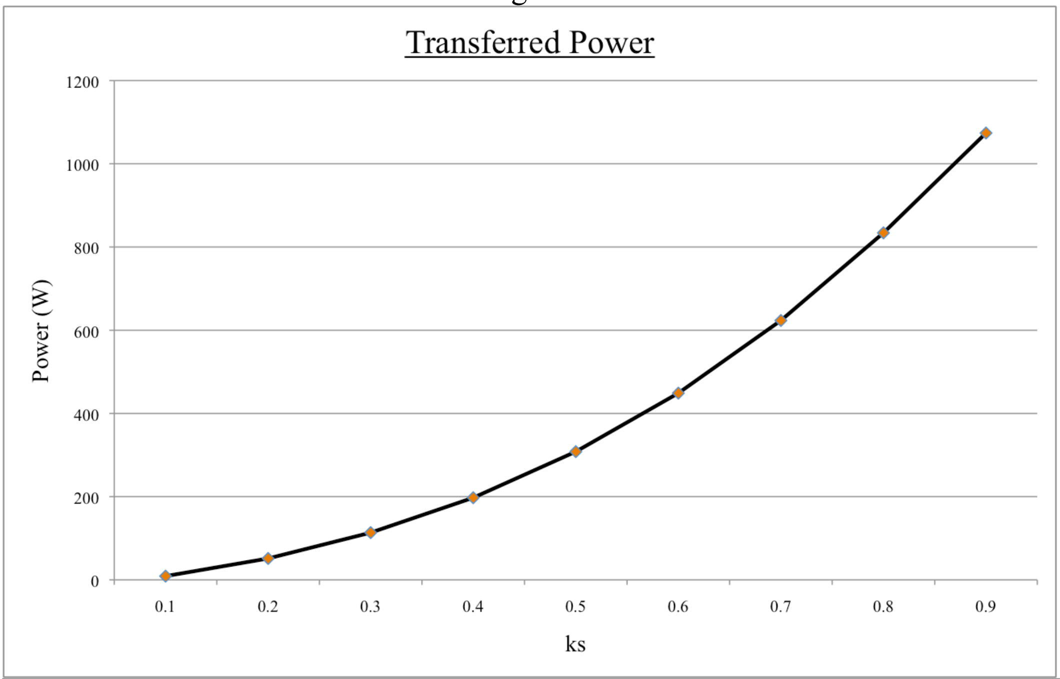
Efficiency:

$$\eta = \frac{P - P_{loss}}{P}$$
$$\eta = \frac{307.94 - 8.927}{307.94} = 0.971 = 97.1\%$$

ks	Am	Ae	P	Pcu	Pfe	Ploss	Efficiency
0.1	0.000312	0.000018792	9.015029989	2.158960767	0.625341101	2.784301868	0.691148907
0.2	0.000624	0.000078408	51.46402942	4.394198239	1.250682202	5.644880441	0.89031406
0.3	0.000936	0.000151848	113.5344623	4.940245466	1.876023302	6.816268769	0.939962998
0.4	0.001248	0.000239112	197.4189934	5.335669387	2.501364403	7.83703379	0.960302534
0.5	0.00156	0.0003402	308.1663159	5.850963584	3.126705504	8.977669088	0.970867455

0.6	0.001872	0.000455112	448.7694684	6.436933279	3.752046605	10.18897988	0.977295737
0.7	0.002184	0.000583848	623.3856077	6.180416326	4.377387706	10.55780403	0.983063767
0.8	0.002496	0.000726408	833.9340722	7.838525495	5.002728806	12.8412543	0.984601595
0.9	0.002808	0.000882792	1073.896178	8.466930761	5.628069907	14.09500067	0.986874894

Note: These values were calculated using the FEM simulation results.



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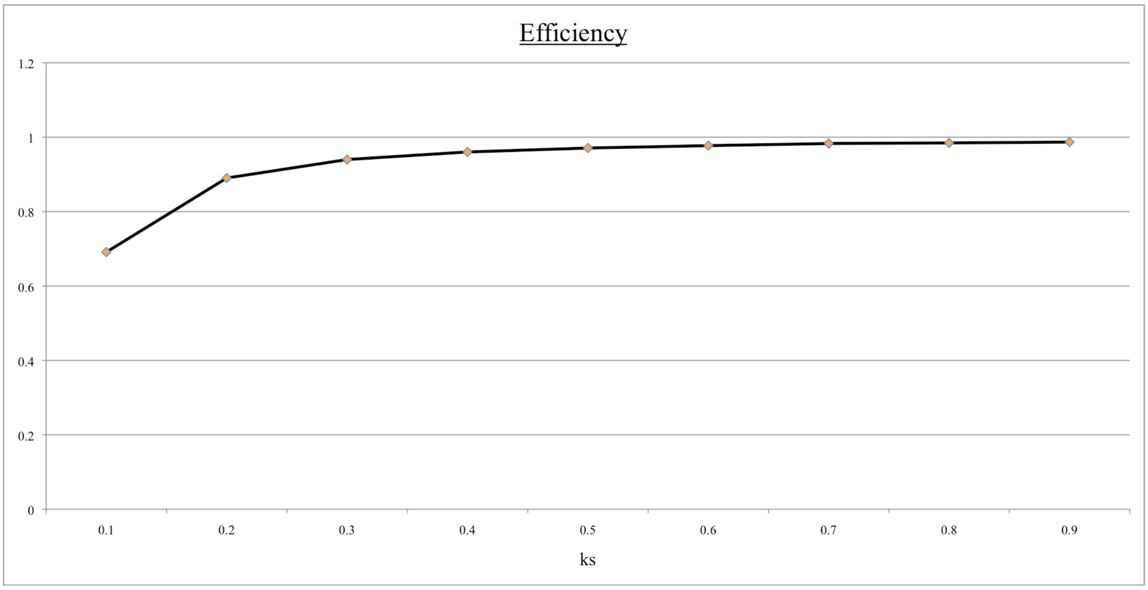

We can observe that although lost power increases with a higher proportion ks, the transferred power rises faster so our efficiency actually rises with the change in ks.

Real Transformer Comparison

The transformer that is closest in size to mine from TRAMO-ETV is the OFL-50 which has Ltr=0.102m, Wtr=0.065m, Hc=0.07m. Compared to my 0.096, 0.08, 0.065 respective sizes.

The power values in the data table are much lower in the real transformer. I assume this is due to a calculation error on my part.