

Assignment 2 Stator Design Part 2 - Joseph Landeg

by Joseph Landeg

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Contents

Abstract	4
Chapter 1 – Introduction	5
1.1 – Efficiency and Flux leakage improvements	5
1.2 – Hysteresis Curve	6
Chapter 2 - Method	8
2.1 – Testing Improvements	10
Chapter 3 - Results	12
3.1 – Flux Leakage in current design (Task 1)	12
3.2 – Minimising Flux Leakage Factor (Task 2)	14
3.2.1 – Experiment 1 (121)	14
3.2.2 – Experiment 2 (131)	15
3.2.3 – Experiment 3 (211)	16
3.2.4 – Experiment 4 (231)	17
3.2.5 – Experiment 5 (311)	18
3.2.6 – Experiment 6 (312)	19
3.2.7 – Experiment 7 (331)	20
3.2.8 – Experiment 8 (332)	21
3.2.9 – Experiment 9 (333)	22
3.2.10 – Complete results	23
Chapter 4 – Discussions	24
Chapter 5 - Conclusions	29
References	30

Figure 1 - Flux Leakage [2].....	6
Figure 2 - Hysteresis Loop [3].....	7
Figure 3 – Current Design.....	8
Figure 4 - Finding Useful Flux	9
Figure 5 - Total Flux.....	9
Figure 6 - Total Flux.....	12
Figure 7 - Useful flux over 90°	12
Figure 8 - Experiment 121	14
Figure 9 - Experiment 131	15
Figure 10 - Experiment 211	16
Figure 11 - Experiment 231	17
Figure 12 - Experiment 311	18
Figure 13 - Experiment 312	19
Figure 14 - Experiment 331	20
Figure 15 - Experiment 332	21
Figure 16 – Experiment 333	22
Figure 17 - Flux Leakage Pattern (%).....	24
Figure 18 - flux leakage changes.....	25
Figure 19 - flux leakage fishtails	26
Figure 20 - Evaluation of Experiment 331	27
Figure 21 - Evaluation of Experiment 311	27
Figure 22 - Comparison of best two experiments	28

Table 1 - Variables	11
Table 2 - Table of Experiment combinations	11
Table 3 - FLF for Experiment 1	14
Table 4 - FLF 131.....	15
Table 5 – FLF 211	16
Table 6 – FLF 231	17
Table 7 – FLF 311	18
Table 8 – FLF 312.....	19
Table 9 - FLF 331.....	20
Table 10 - FLF 332.....	21
Table 11 – FLF 333.....	22
Table 12 - Comparison of flux leakage factor	23

Abstract

Using FEMM 4.2 to design a DC motor stator circuit model, flux leakage factor will be evaluated.

A series of tests were carried out to evaluate the flux leakage factor of each combination of variables to achieve the most efficient motor, meaning the lowest flux leakage factor.

Only specific parts of the circuit can be altered such as stator radius, armature width and adding fishtails. The properties of the coils or outside diameter of the stator cannot be altered.

The most efficient motor was found to have the highest stator radius in the tests with the armature width wider than initial design. The efficiency was found to increase to 45.80%, meaning a flux leakage factor of 54.20%.



Chapter 1 – Introduction

Using a DC stator model, inefficiencies of magnetic flux leakage will be analysed using FEMM. The flux leakage factor is obtained from the software to indicate how efficient the system is. Specific changes to the motor stator design will be made to analyse changes in flux leakage, therefore, improving the efficiency of the motor.

1.1 – Efficiency and Flux leakage improvements

Efficiency is the outcome of useful energy compared to total energy supplied to a system [1], given as a percentage by:

$$\text{Efficiency} = \text{Energy Out} / \text{Energy In} \times 100\%$$

The efficiency of this system is based on total magnetic flux density compared to useful flux density of the DC motor stator circuit. The equation for obtaining flux leakage factor:

$$\text{Flux Leakage} = \text{Total} - \text{Useful} / \text{Total} (\times 100\%)$$

$$\text{Efficiency} = 100\% - \text{Flux Leakage}$$

Flux leakage is defined as the magnetic flux which flows outside the path in which it is useful [2]. To minimise flux leakage, the magnetic flux density in the iron stator should be larger than flux in air gap [2].

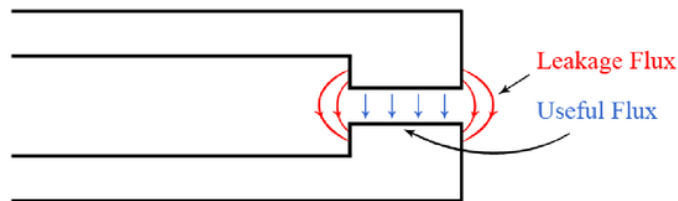


Figure 1 - Flux Leakage [2]

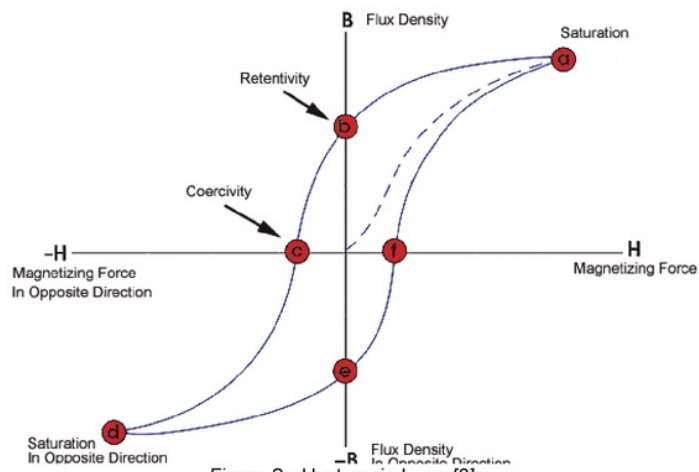
It's not only the magnetic flux that effects motor efficiency. There are losses that effect efficiency such as heat, friction, hysteresis losses etc.

1.2 – Hysteresis Curve

It's important to understand the hysteresis curve to know where losses occur in terms of the magnetic properties.

Figure.2 shows as the magnetic force increases in one polarity, the flux density increases, until it gets to saturation point where a material cannot improve its density further. As polarity changes, magnetic force is applied in opposite direction therefore, the flux density follows in opposite direction until saturation.

The hysteresis losses occur when the polarity of the rotor changes, **B – C** and **E – F** [3].



However, for this system the effect flux density has on efficiency will be analysed.

Chapter 2 - Method

The total flux density of the stator circuit will be obtained to evaluate a flux leakage factor for current system.



Figure 3 – Current Design

Improvements will be made to current design to enhance the efficiency of the motor by reducing the flux leakage factor.

A combination of tests will be carried out after each alteration to analyse what changes has the biggest impact on efficiency.

By creating nodes within the rotor in increments of 5° up to 90° in both north/south poles of motor, the highest value of useful flux can be obtained and applied to an equation along with the total flux to obtain the flux leakage factor.

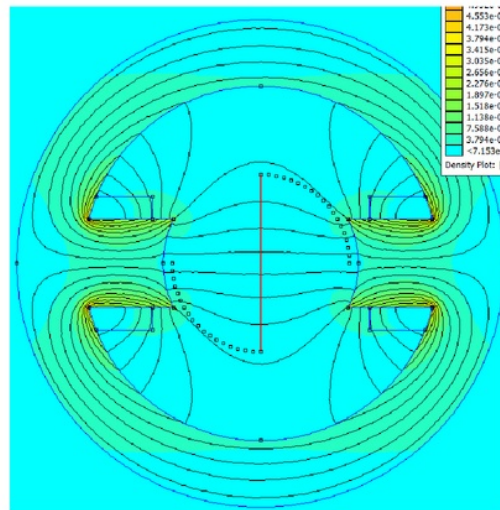


Figure 4 - Finding Useful Flux

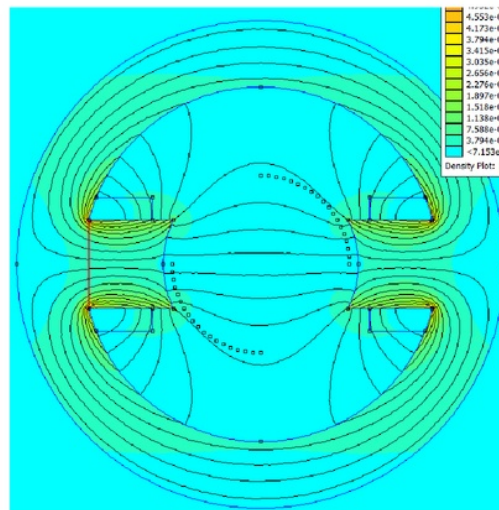


Figure 5 - Total Flux

2.1 – Testing Improvements

The specific properties of the motor that can be changed are as follows:

Variables:

- Armature Width
- Stator Radius
- Armature face (fishtail)

Non-Variable:

- Outer radius
- Armature Radius
 - Materials
- Coil properties

The changes that will be carried out will include:

	Stator Radius (V1)		Armature Width (V2)		Fishtail (V3)
1	40mm (Current)	1	20mm (Current)	1	None (Current)
2	45mm	2	10mm	2	Small
3	50mm	3	30mm	3	Large

Table 1 - Variables

These are the variables chosen to be tested in a variety of combinations, to cover every possibility and achieve most efficient motor.

Experiment	V1	V2	V3
Current Specification	1	1	1
1	1	2	1
2	1	3	1
3	2	1	1
4	2	3	1
5	3	1	1
6	3	1	2
7	3	3	1
8	3	3	2
9	3	3	3

Table 2 - Table of Experiment combinations

Chapter 3 - Results

3.1 – Flux Leakage in current design (Task 1)

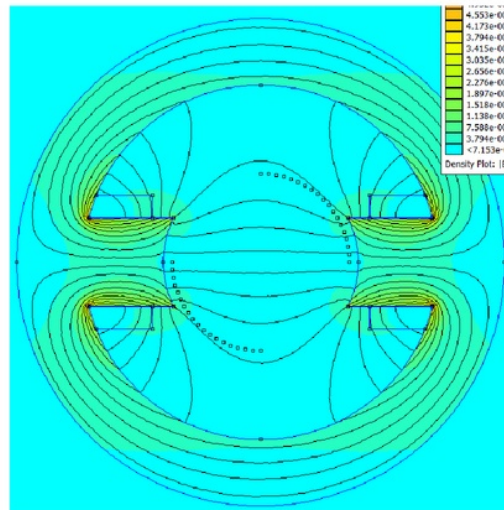


Figure 6 - Total Flux

Total flux in current design was evaluated as 238.6E-06.



Angle	X	Y	Phi (Wb)
0	20	0	9.26E-09
5	19.92389	1.743115	-1.06E-05
10	19.69616	3.472964	-2.17E-05
15	19.31852	5.176381	-3.34E-05
20	18.79385	6.840403	-4.65E-05
25	18.12616	8.452365	-6.11E-05
30	17.32051	10	-7.39E-05
35	16.38304	11.47153	-8.08E-05
40	15.32089	12.85575	-8.40E-05
45	14.14214	14.14214	-8.52E-05
50	12.85575	15.32089	-8.53E-05
55	11.47153	16.38304	-8.50E-05
60	10	17.32051	-8.44E-05
65	8.452365	18.12616	-8.37E-05
70	6.840403	18.79385	-8.31E-05
75	5.176381	19.31852	-8.25E-05
80	3.472964	19.69616	-8.20E-05
85	1.743115	19.92389	-8.18E-05
90	1.23E-15	20	-8.17E-05

Figure 7 - Useful flux over 90°



The highest value for useful flux was evaluated at 50°, with a value 8.53E-05.

Therefore, the flux leakage factor is:

$$\text{FLF} = (238.6\text{E-}06) - (8.53\text{E-}05) / (238.6\text{E-}06) \times 100$$

$$\text{Flux Leakage Factor} = 64.25\%$$

3.2 – Minimising Flux Leakage Factor (Task 2)

3.2.1 – Experiment 1 (121)

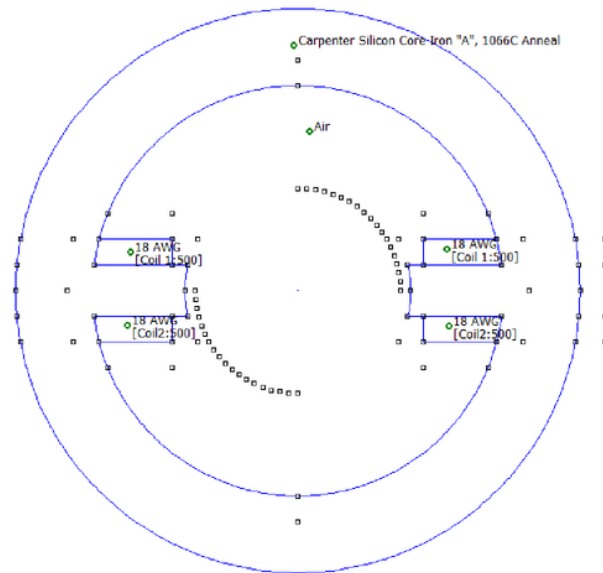


Figure 8 - Experiment 121

Angle	X	Y	Phi (Wb)		
40	15.32089	12.85575	-6.43E-05		
50	12.85575	15.32089	-6.38E-05		
60	10	17.32051	-6.23E-05		
				Total Flux	0.000189
				Useful Flux	6.43E-05
					66.05%

Table 3 - FLF for Experiment 1

3.2.2 – Experiment 2 (131)

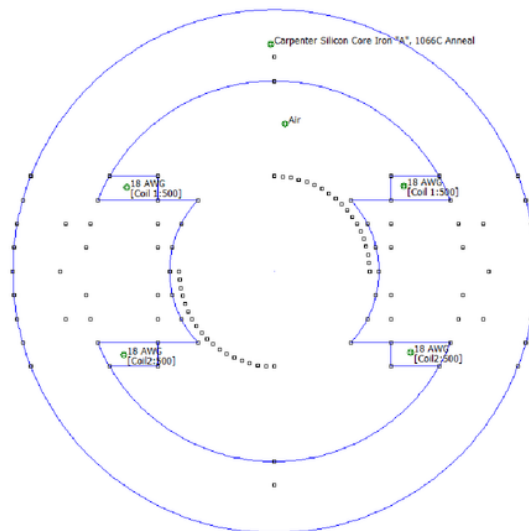


Figure 9 - Experiment 131

Angle	X	Y	Phi (Wb)			
40	15.32089	12.85575	-6.93E-05			
50	12.85575	15.32089	-9.78E-05			
60	10	17.32051	-1.09E-04			
70	6.840403	18.79385	-0.00011			
					Total Flux	0.000311
					Useful Flux	0.00011
					FLF	64.47%

Table 4 - FLF 131

3.2.3 – Experiment 3 (211)

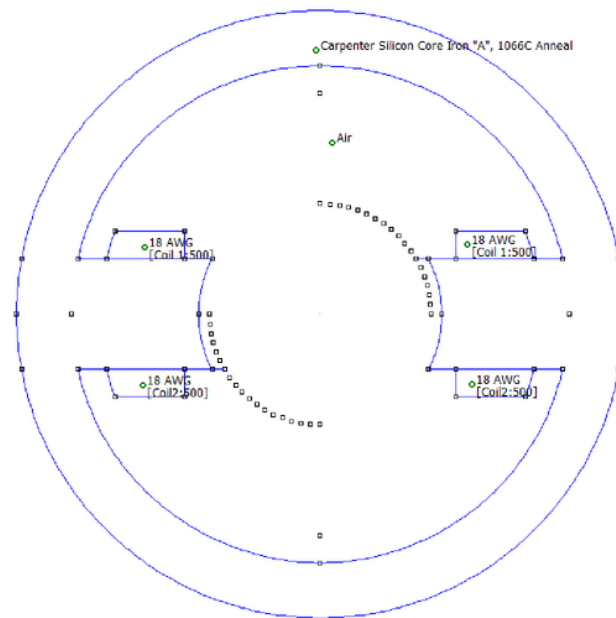


Figure 10 - Experiment 211

Angle	X	Y	Phi (Wb)			
40	15.32089	12.85575	-8.00E-05			
50	12.85575	15.32089	-8.50E-05			
60	10	17.32051	-8.57E-05			
					Total Flux	0.000205
					Useful Flux	8.57E-05
						58.15%

Table 5 – FLF 211

3.2.4 – Experiment 4 (231)



Figure 11 - Experiment 231

Angle	X	Y	Phi (Wb)			
40	15.32089	12.85575	-8.33E-05			
50	12.85575	15.32089	-1.05E-04			
60	10	17.32051	-1.10E-04			
70	6.840403	18.79385	-0.00011			
80	3.472964	19.69616	-0.00011			
90	1.23E-15	20	-0.00011		Total Flux	0.000266
					Useful Flux	-0.00011
					FLF	58.11%

Table 6 – FLF 231

3.2.5 – Experiment 5 (311)

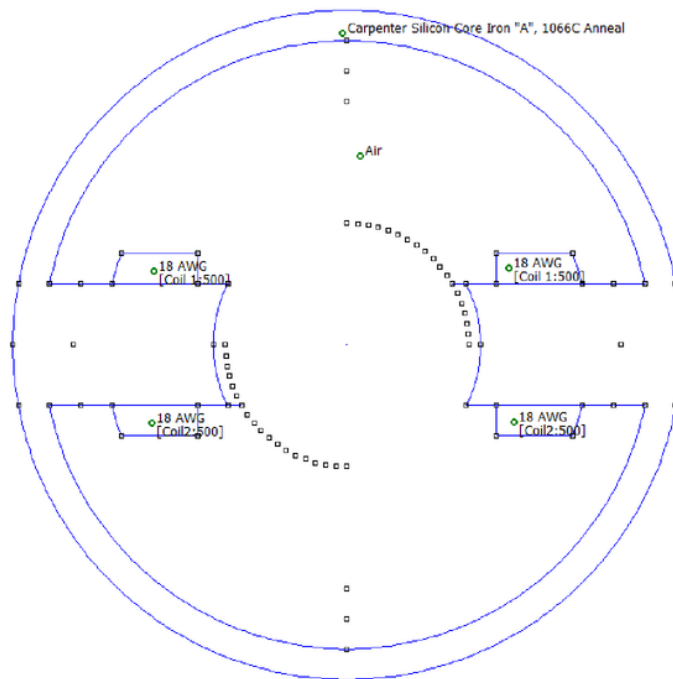


Figure 12 - Experiment 311

Angle	X	Y	Phi (Wb)		
40	15.32089	12.85575	-7.95E-05		
50	12.85575	15.32089	-8.48E-05		
60	10	17.32051	-8.59E-05		
				Total Flux	0.000187
				Useful Flux	8.59E-05
					54.21%

Table 7 – FLF 311

Note: As the stator radius is increased, the efficiency of the motor increases. The stator radius can only get to a particular size before the useful flux gets so low that iron outside won't be able to withhold flux density required.

3.2.6 – Experiment 6 (312)

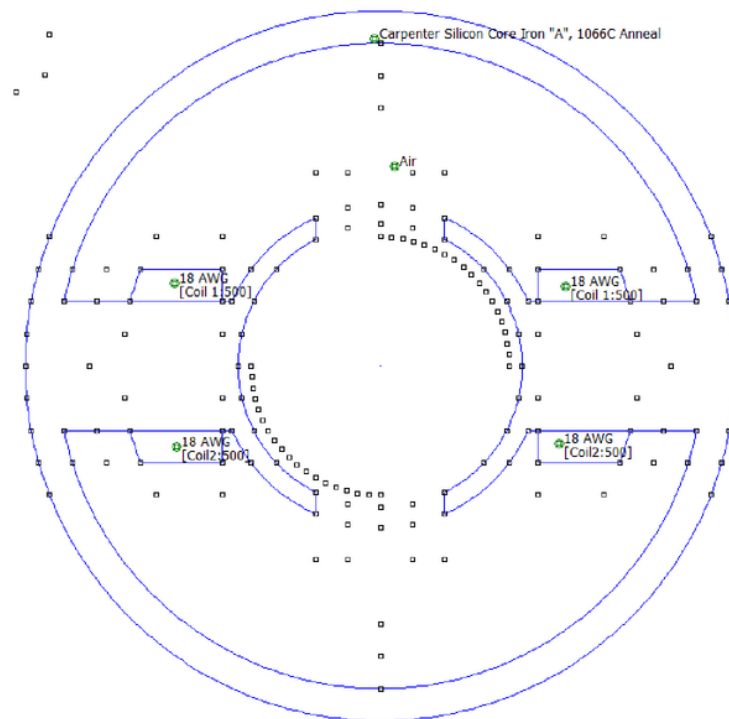


Figure 13 - Experiment 312

Angle	X	Y	Phi (Wb)			
40	15.32089	12.85575	-6.43E-05			
50	12.85575	15.32089	-8.67E-05			
60	10	17.32051	-1.17E-04			
70	6.840403	18.79385	-0.00015			
80	3.472964	19.69616	-0.00016			
90	1.23E-15	20	-0.00016	Total Flux	0.000411	
				Useful Flux	-0.00016	
				FLF	61.68%	

Table 8 – FLF 312

3.2.7 – Experiment 7 (331)

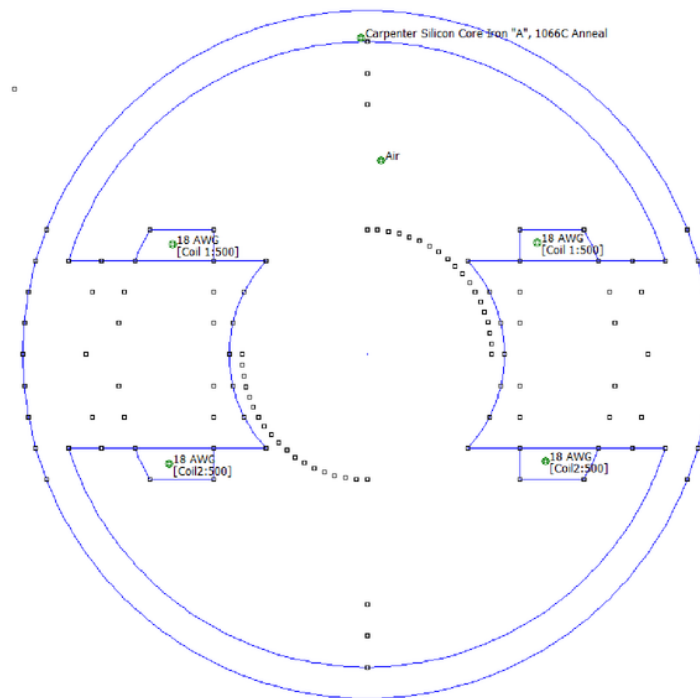


Figure 14 – Experiment 331

Angle	X	Y	Phi (Wb)			
40	15.32089	12.85575	-8.28E-05			
50	12.85575	15.32089	-1.04E-04			
60	10	17.32051	-1.10E-04			
70	6.840403	18.79385	-0.00011			
80	3.472964	19.69616	-0.00011			
90	1.23E-15	20	-0.00011		Total Flux	0.000245
					Useful Flux	-0.00011
					FLF	54.20%

Table 9 – FLF 331

3.2.8 – Experiment 8 (332)

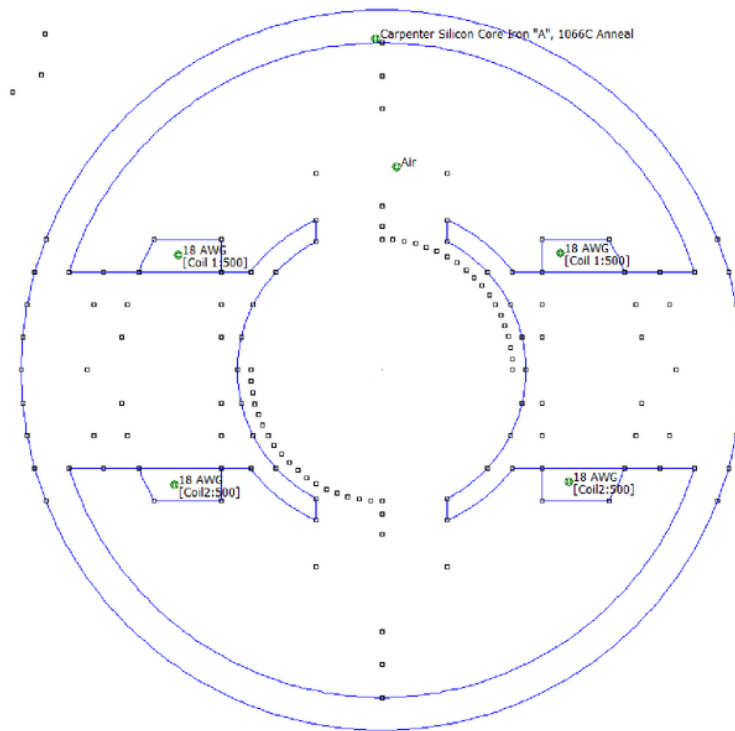


Figure 15 - Experiment 332

Angle	X	Y	Phi (Wb)		
40	15.32089	12.85575	-6.44E-05		
50	12.85575	15.32089	-8.69E-05		
60	10	17.32051	-1.17E-04		
70	6.840403	18.79385	-0.00015		
80	3.472964	19.69616	-0.00016		
90	1.23E-15	20	-0.00016	Total Flux	0.000395
				Useful Flux	-0.00016
				FLF	59.07%

Table 10 - FLF 332

3.2.9 – Experiment 9 (333)

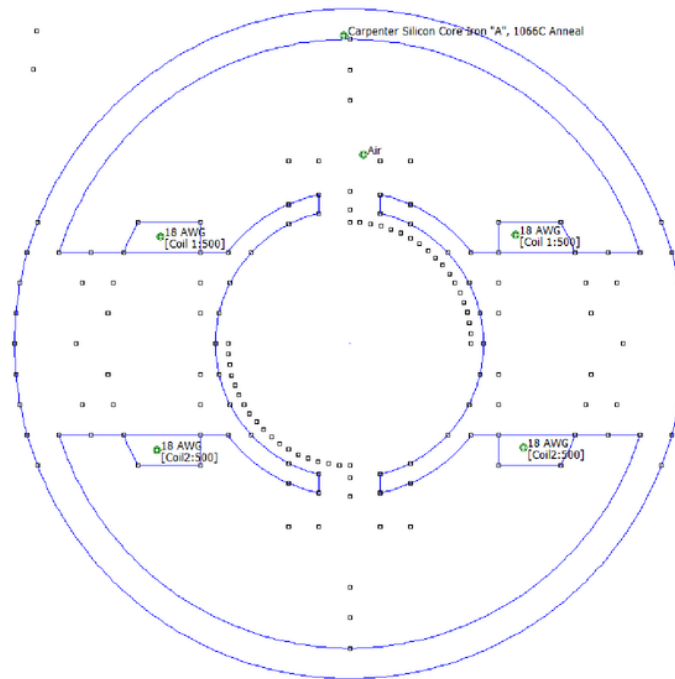


Figure 16 – Experiment 333

Angle	X	Y	Phi (Wb)		
40	15.32089	12.85575	-6.10E-05		
50	12.85575	15.32089	-8.10E-05		
60	10	17.32051	-1.06E-04		
70	6.840403	18.79385	-0.00014		
80	3.472964	19.69616	-0.00018		
90	1.23E-15	20	-0.0002	Total Flux	0.000553
				Useful Flux	-0.0002
				FLF	63.65%

Table 11 – FLF 333

3.2.10 – Complete results

V1	V2	V3	Total Flux	Max Useful Flux	Flux Leakage Factor (%)
1	1	1	2.39E-04	8.53E-05	64.22%
1	2	1	1.89E-04	6.43E-05	66.05%
1	3	1	3.11E-04	1.10E-04	64.47%
2	1	1	2.05E-04	8.57E-05	58.15%
2	3	1	2.66E-04	1.10E-04	58.11%
3	1	1	1.87E-04	8.59E-05	54.21%
3	1	2	4.11E-04	-1.61E-04	61.68%
3	3	1	2.45E-04	1.10E-04	54.20%
3	3	2	3.95E-04	1.60E-04	59.07%
3	3	3	5.53E-04	2.00E-04	63.65%

Table 12 - Comparison of flux leakage factor

Note: Experiment 111 is the current design before any changes are made, for comparison only.

Chapter 4 – Discussions

Each variable has been tested by keeping two variables the same throughout, then changing one variable to analyse what impact one has.

This resulted in showing a pattern for each variables.

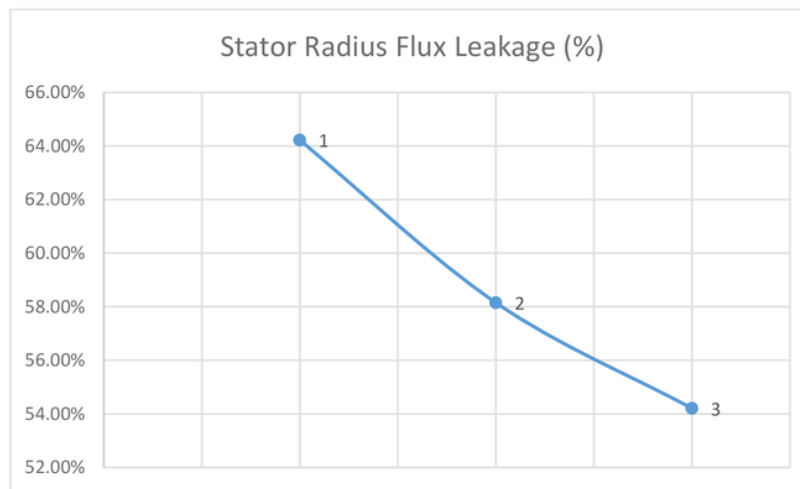


Figure 17 - Flux Leakage Pattern (%)

Figure.17 shows as the stator radius is increased, the flux leakage factor decreases, improving efficiency.

The next experiment was to only alter the armature width to evaluate the effect this has on the model.

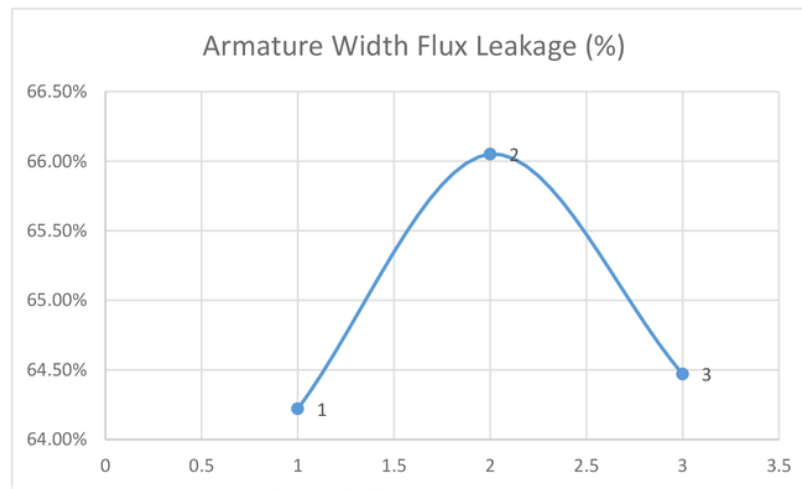


Figure 18 - flux leakage changes

Figure.18 is interesting because it shows that when the armature width is 10mm, the flux leakage factor increases meaning the efficiency of the motor gets worse. However, when the armature width is 30mm, the leakage factor improves but it does not get better than current design.

However, as experiment 331 shows, the flux leakage factor is lowest when stator radius is 50mm and armature width is 30mm.

As it has been proven that flux leakage factor improves when the stator radius is increased and with an armature width of 30mm, fishtail experiments were all done with stator radius at 50mm and armature at 30mm.

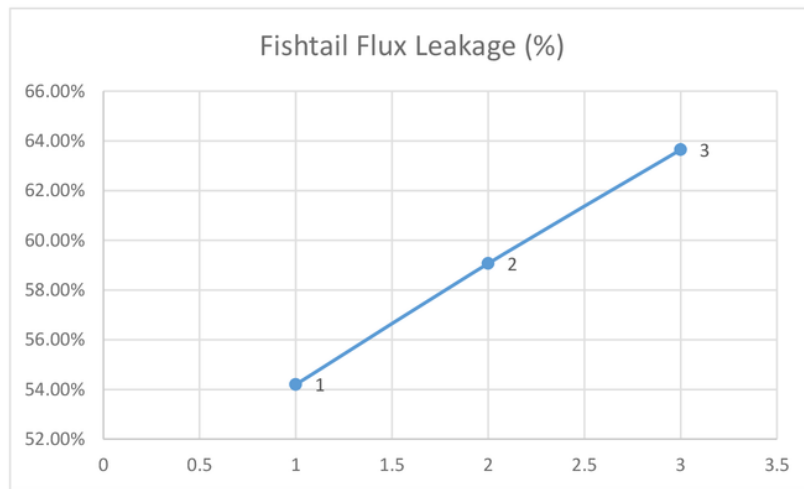


Figure 19 - flux leakage fishtails

As shown, when fishtails are added to the model, flux leakage factor increases, lowering the efficiency further.

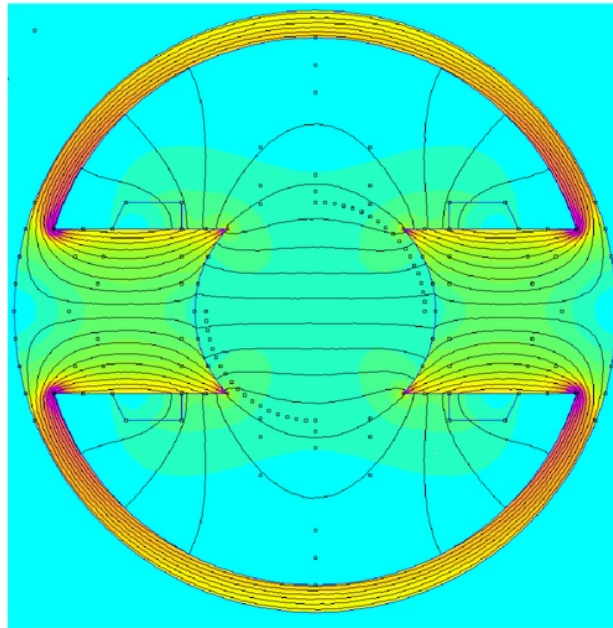


Figure 20 - Evaluation of Experiment 331

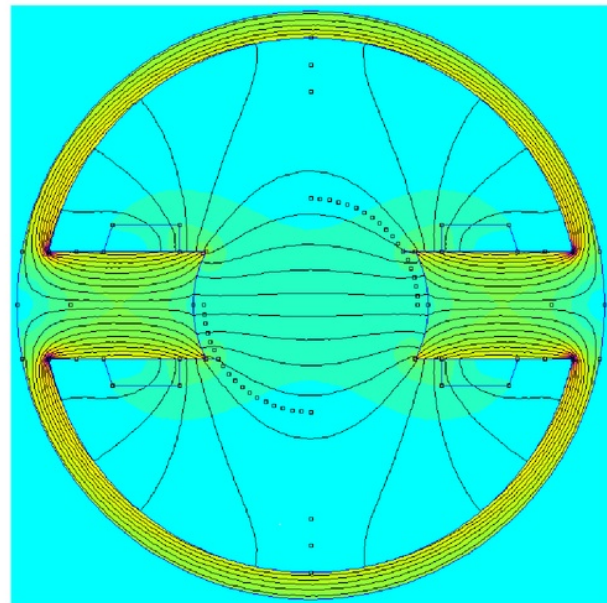


Figure 21 - Evaluation of Experiment 311

Figure. 20 and 21 shows the evaluation of experiment 331 and 311 respectively. It shows the flux lines cutting through the rotor are roughly the same.

	Total Flux	Useful Flux (Max)	Flux Leakage Factor (%)
311	1.87E-04	8.59E-05	54.21%
331	2.45E-04	1.10E-04	54.20%

Figure 22 - Comparison of best two experiments

Even though the two experiments have the best efficiency, experiment 331 generates a higher total flux and has more useful flux than 311. For this reason the latter will be used as most efficient design.

Having a flux leakage factor of 54.20%, compared to original design of 64.22%, experiment 331 has an improvement of 10.02%. Meaning the motor is 45.80% efficient.

Throughout the experiments the total flux in the motor did increase with different alteration, however, this flux was not directed through the rotor resulted in being wasted.

Chapter 5 - Conclusions

Throughout this task, I learned how important properties and design of a DC motor stator circuit are to achieve the most efficient output in terms of flux density.

There are many aspects of a stator that can be changed to increase total flux density within the circuit, however these changes can lead to the total flux not being useful for work, meaning that the total flux density is wasted if this is the case.

If the modifications to the circuit are utilised correctly, then the total flux density generated within the circuit is used to cut through the rotor creating a more efficient work.

I have also learned how each variable applied in different combinations with each other can affect flux density in a circuit and how each one effects flux leakage factor.

Finally, the skill to analyse different circuits on FEMM 4.2 has been obtained and how to carry out tests to ensure that the combinations being used are showing the best possible results with limited experiments.

References

- [1] "Dictionary.com," [Online]. Available: <https://www.dictionary.com/browse/efficiency>. [Accessed 18 March 2019].
- [2] "Magnetic Leakage," [Online]. Available: <https://www.codecogs.com/library/physics/magnetism/magnetic-leakage.php>. [Accessed 18 March 2019].
- [3] "The Hysteresis Loop and Magnetic Properties," [Online]. Available: <https://www.nde-ed.org/EducationResources/CommunityCollege/MagParticle/Physics/HysteresisLoop.htm>. [Accessed 18 March 2019].

Assignment 2 Stator Design Part 2 - Joseph Landeg

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

69/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4



Comment 1

Nice abstract. All relevant information present. Flows well, although you have mixed your tenses: in the first sentence you say "...flux leakage factor **will be** evaluated." and the next sentence you say "... tests **were** carried out to..". You should write in past tense as it is work you have already done.

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12



Comment 2

units?

PAGE 13



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PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

GRADING FORM: SMU GENERIC_SMOSEY

JOSEPH LANDEG

68.70

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



References to a limited range of material. The material you reference should be from more reputable sources such as peer reviewed journals, theses submitted to universities, textbooks and other academic writing. Referencing conventions adhered to throughout report.

4.8

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.

21.3

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Thoroughly logical work, supported by evaluated evidence. High quality analysis. You have shown the ability to investigate contradictory information and identify reasons for contradictions.

21.3

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods and techniques. Creativity evident throughout.

14.2

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate professionally and, confidently in a suitable format. Work is coherent, very fluent and is presented professionally.

7.1