

El Mach Assign 1

by Derek Lockhart

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Stator Modelling Part 1

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1. Abstract

A finite element method analysis of a DC Motor Stator, including flux density and flux leakage factor analysis of the given model. A model created in FEMM software to analyse maximum flux generated and max useable flux as a function of angle to deduce flux leakage factor, demonstrating the angle at which maximum useful flux is intersected.

2. Introduction

This paper shall complete a finite element method simulation of a flux characteristics of a given DC motor stator and carry out an analysis of the results. Using this simulation, the flux leakage factor shall be defined and show the consequent effectiveness of the design.

2.1 DC Motors

DC motors work due to the interaction of the magnetic fields of the Stator and the Rotor, the four main types of DC Motor are defined by the methods by which the fields are produced or their electrical connection[1]. Permanent magnet motors use, as the name suggests, permanent magnet to produce the stator field. Series DC Motors are separated from shunt DC motors by the electrical configuration of the of the stator field with respect to the armature. Compound DC motors combine series and shunt connections to gain the advantages of the torque performance of a series motor and the speed control advantages of a shunt wound motor[2][3][4]. Irrespective of the type of motor, a method of changing electrical polarity is required during rotation, in a simple brushed motor this is done by a commutator and in a brushless motor by a switching circuit in the motor controller[5].

2.2 Magnetics

The magnetic fields of DC motors and their interactions are the source of the motor torque. The Factors affecting the strength of the magnetic field poles are the current, the number of turns in the coil and the coil length in a excited circuit or the type and strength of the permanent magnet. Magnetic field strength (H , in A/m) is a measure of the field a given distance from magnetic source[6]. Whilst the magnetic flux density (B , in Teslas) is proportional to the field strength, its magnitude is a factor of the permeability of the core used[7]. The units are linked by the equation $B=\mu_r H$, where μ_r is the relative permeability of the core.

Magnetic fields are only useful where they interact, therefore the distance between them and the angle at which they meet, will define the torque produced. The angle at which they meet is defined as the load angle[8], or torque angle. The amount of torque produced is the sine of the angle, therefore at 90° the maximum torque shall be induced[9], this however is only relevant to the amount of flux “cut” by the armature, which in this exercise means that the maximum torque will be at the angle of maximum useable flux.

2.3 Finite Element Method

This exercise will use the finite element method (FEM) to calculate the flux characteristics of a given motor stator. FEM is a way of simplifying a very complex calculation, an approximation is created based on effects that can be calculated at discrete points and/or intervals[10][11]. These calculated effects can then be combined to give a close approximation of the whole system. The more numerous the approximations, then the more accurate the final calculation. However, the number of approximations attempted must be

within the capabilities of the processing system to realise a valid answer in a reasonable time[12]. In this instance the FEMM (Finite Element Method Magnetics) software package[13] shall be used which is designed to solve low frequency electromagnetic problems using finite element method.

2.4 Task specifics

The stator dimensions to be tested are as given in the task description[14]. The stator is shown in Figure 1 and the specifications shown in Table 1.



Figure 1 DC Motor Stator

Dimension	Size
Depth of Circuit	100mm
Outside Stator Diameter	110mm
Inside Stator Diameter	80mm
Pole Face Radius	22mm
Pole Widths	20mm
Field Generating Coil Vertical Coordinates	±15mm
Field Generating Coil Horizontal Internal Coordinates	±24.5mm
Rotor Coil Width	40mm
Field Generating Coil Current	±1A
Field Generating Coils Number of Turns: 500	500

Table 1 DC Motor Stator Specifications

3. Method

Using the given parameters, the solution shown in Figure 2 was plotted in the FEMM software.

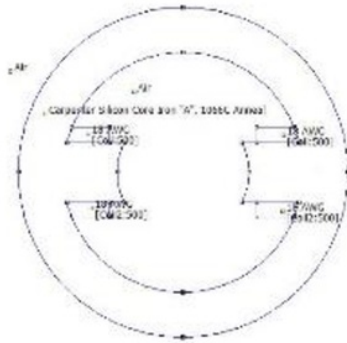


Figure 2 DC Motor Stator Model

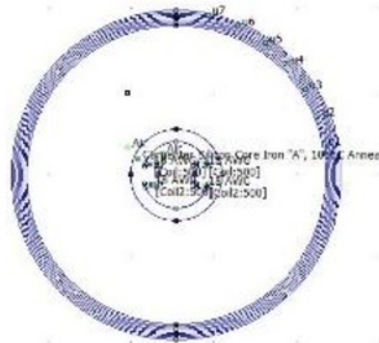


Figure 3 DC Motor Stator Model with Boundaries

The Finite element method requires limits to be placed on the size of the model that will be simulated, boundaries, these boundaries will limit the free space calculations that will be completed beyond that stator dimensions. This boundary is shown in Figure 3.

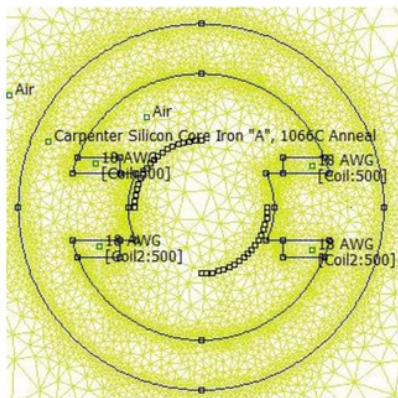


Figure 4 FEMM Mesh

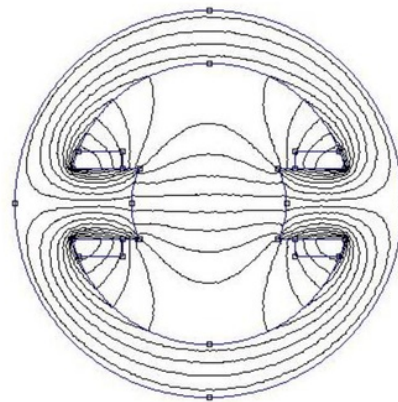


Figure 5 FEMM Solution

The FEMM mesh system defines the discrete points used in the approximation, this is shown in Figure 4. The solution calculated by the FEMM software can be seen in Figure 5.

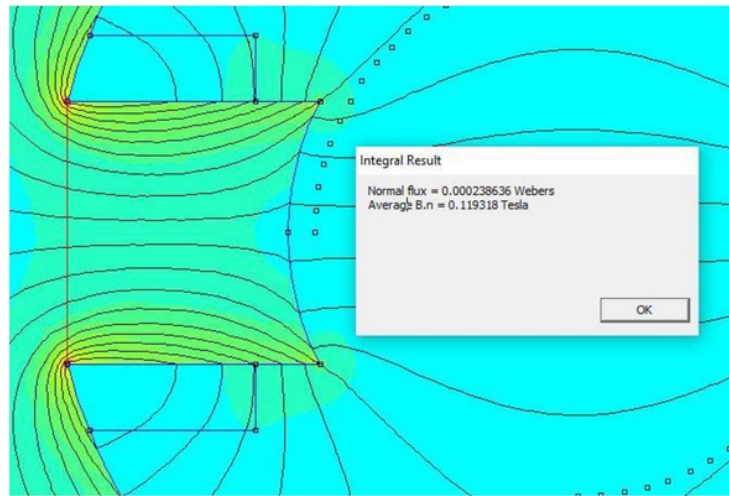


Figure 6 Flux density on colour scale

Further detail can be seen in Figure 6 which shows the flux density as a colour scale. This also allows the measurement of the maximum flux generated, in a similar manner the flux dissected by the armature at discrete angles may be measured. The positions of the armature at various angles is calculated using the following equations, all co-ordinates with respect to the armature centre (0,0), $X = radius * Cos \theta$ $Y = radius * Sin \theta$.

End 1					
θ	X	Y	θ	X	Y
0	-20.0	0.0	50	-12.9	15.3
5	-19.9	1.7	55	-11.5	16.4
10	-19.7	3.5	60	-10.0	17.3
15	-19.3	5.2	65	-8.5	18.1
20	-18.8	6.8	70	-6.8	18.8
25	-18.1	8.5	75	-5.2	19.3
30	-17.3	10.0	80	-3.5	19.7
35	-16.4	11.5	85	-1.7	19.9
40	-15.3	12.9	90	0.0	20.0
45	-14.1	14.1			

End 2					
θ	X	Y	θ	X	Y
0	20.0	0.0	50	12.9	-15.3
5	19.9	-1.7	55	11.5	-16.4
10	19.7	-3.5	60	10.0	-17.3
15	19.3	-5.2	65	8.5	-18.1
20	18.8	-6.8	70	6.8	-18.8
25	18.1	-8.5	75	5.2	-19.3
30	17.3	-10.0	80	3.5	-19.7
35	16.4	-11.5	85	1.7	-19.9
40	15.3	-12.9	90	0.0	-20.0
45	14.1	-14.1			

Table 2 Armature co-ordinates relative to centre

4. Results

The maximum flux generated can be found across the base of the poles, as seen in Figure 6. This was calculated by the FEMM software as 2.38636×10^{-4} Webers.

θ	Useful Flux	θ	Useful Flux
0	-1.12E-07	50	-8.52E-05
5	-1.03E-05	55	-8.50E-05
10	-2.17E-05	60	-8.42E-05
15	-3.34E-05	65	-8.36E-05
20	-4.59E-05	70	-8.30E-05
25	-6.12E-05	75	-8.24E-05
30	-7.35E-05	80	-8.21E-05
35	-8.08E-05	85	-8.17E-05
40	-8.37E-05	90	-8.17E-05
45	-8.44E-05		

Table 3 Flux cutting by coil angle

Using the coordinates available in Table 2 the flux at various angles was measured, the results shown in Table 3. The flux leakage factor is a figure for the amount of generated flux lost to the air outside the radius of the armature[15]. The maximum useable flux is 8.52×10^{-5} Webers. At 50°

The flux leakage factor is calculated thus:

$$\text{Flux Leakage Factor} = \frac{\text{Max Flux} - \text{Max Useable Flux}}{\text{Max Flux}}$$

$$\text{Flux Leakage Factor} = \frac{2.38636 \times 10^{-4} - 8.52 \times 10^{-5}}{2.38636 \times 10^{-4}}$$

$$\text{Flux Leakage Factor} = 0.643 \text{ (64.3\%)}$$

5. Conclusions

This exercise has demonstrated that the maximum flux generated in a stator coil is not all intersected by an armature, in this case almost two thirds of all the flux generated is ineffectual. Alterations to the design of the stator would be advisable to increase the effectiveness of the system.

The angle of the armature with respect to the pole arms affects the magnitude of the flux intersected, it could be assumed that the maximum flux would be intersected at 90° , Table 3 shows this is not the case. When plotting the information in Table 3 maximum useable flux is found at an angle of approximately 50° , the reason for this can be seen in Figure 5, where lines of flux are shown taking a circuitous route between the poles, should this route plot outside the radius of the armature then the flux is not effectual.

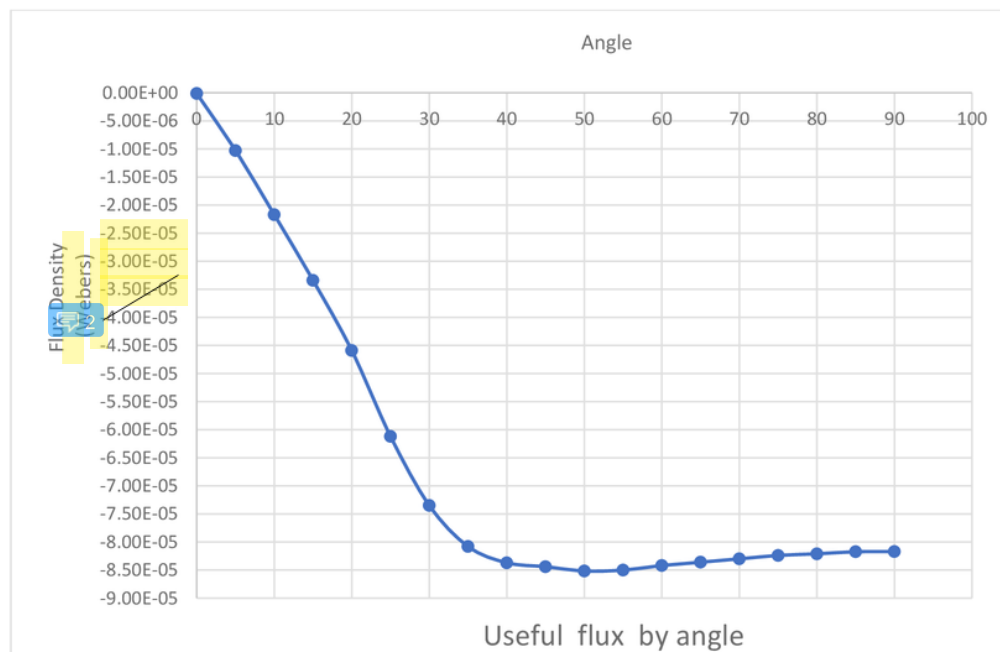


Figure 7 Graph of useful flux by armature angle

Figure 7 shows the useable flux density across the first 90° of rotation, this can be extended through the full 360° and can be seen in Figure 8.

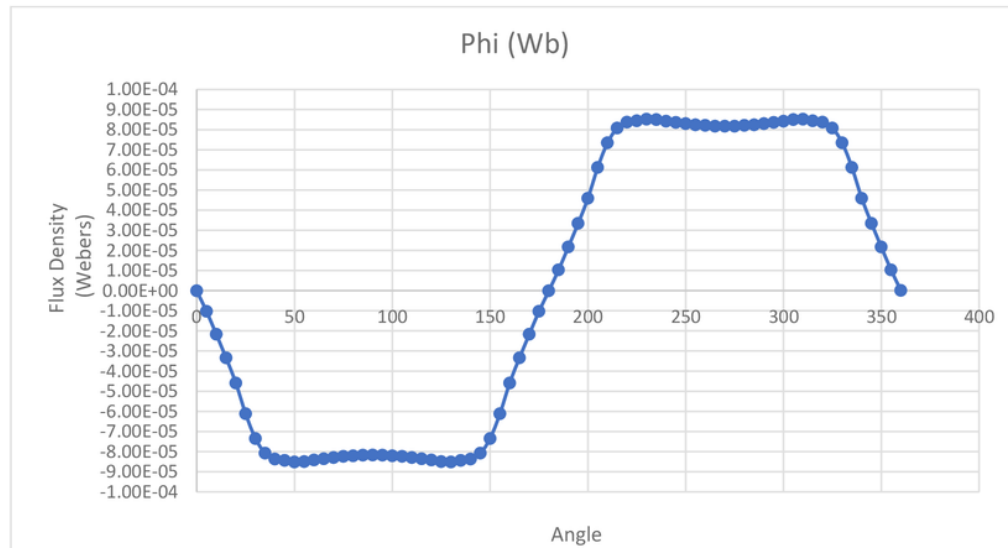


Figure 8 Graph of Useful flux over 360 degrees

Figure 8 shows that, as would be expected, the maximum useable flux is found at the same angle with each quadrant of rotation, therefore any improvement in the intersection of flux due to design changes and consequent reduction of flux leakage would improve the efficiency of the system in all four quadrants.

6. References

- [1] A. Hughes and B. Drury, *Electric motors and drives : fundamentals, types and applications*. Newnes, 2013.
- [2] S. N. Vukosavić, *Electrical machines*. Springer, 2013.
- [3] Microchip Technology Inc, 'Brushed DC Motor Fundamentals', Chandler, 2018.
- [4] Electrical Power Energy .com, 'Direct Current Motor Advantages and Disadvantages', *DC Motors*, 2017. [Online]. Available: <http://www.electricalpowerenergy.com/2017/05/03/direct-current-motor-advantages-and-disadvantages/>. [Accessed: 09-Mar-2019].
- [5] N. Matsui and M. Shigyo, 'Brushless DC motor control without position and speed sensors', *IEEE Trans. Ind. Appl.*, vol. 28, no. 1, pp. 120–127, 1992.
- [6] S. B. Ozturk and H. A. Toliyat, 'Direct Torque and Indirect Flux Control of Brushless DC Motor', *IEEE/ASME Trans. Mechatronics*, vol. 16, no. 2, pp. 351–360, Apr. 2011.
- [7] F. Rao, G. Gu, Zhongguo dian gong ji shu xue hui., Zhongguo ke xue yuan. Dian gong yan jiu suo., and IEEE Industry Applications Society., *ICEMS2003 : proceedings of the Sixth International Conference on Electrical Machines and Systems : November 9-11, 2003, Beijing, China*. International Academic Publishers/ Beijing World Pub. Corp, 2003.
- [8] E. DeVillers, J. LeBesnerais, M. Hecquet, and J.-P. LeCointe, 'Effect of the load angle on radial and tangential magnetic forces in Permanent Magnet Synchronous Machines', *Bethune*, 1, 2016.

- [9] 'D.C. Motor Torque/Speed Curve Tutorial', *MIT Tutorials*, 2011. [Online]. Available: <http://lancet.mit.edu/motors/motors3.html>. [Accessed: 09-Mar-2019].
- [10] D. L. Logan, *A first course in the finite element method*, 5th ed. Stamford: Cengage Learning, 2012.
- [11] W. Li, B. Song, and Y. Hu, 'Numerical Simulation of a Leakage Magnetic Flux for Permanent Magnet DC Motors', in *2011 Second International Conference on Digital Manufacturing & Automation*, 2011, pp. 788–791.
- [12] M. Golebiowski, 'Improvement of the finite element method equations conditioning for the magnetic field-circuit problems', *Arch. Electr. Eng.*, vol. 66, no. 2, pp. 325–337, 2017.
- [13] D. Meeker, 'Finite Element Method Magnetics: HomePage', *femm.info*, 2019. [Online]. Available: <http://www.femm.info/wiki/HomePage>. [Accessed: 06-Mar-2019].
- [14] S. Mosey, 'Course: L6 - Electrical Machines (M6X00373)', *UWTSD-Moodle-M6X00373*, 2019. [Online]. Available: <https://moodle.uwtsd.ac.uk/course/view.php?id=2495>. [Accessed: 06-Mar-2019].
- [15] A. Hughes, *Electric motors and drives : fundamentals, types, and applications*, 2nd ed. Oxford: Newnes, 1993.

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

76/100

Instructor

PAGE 1

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PAGE 3



Comment 1

Nice abstract, but you should include some results.

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Comment 2

Flux is measured in Webbers, Flux density is measured in Tesla

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PAGE 11

PAGE 12

DEREK LOCKHART

76.40

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Outstanding knowledge of research-informed literature embedded in the work. Outstanding selection of relevant and credible sources. High-level referencing skills consistently and professionally applied.

8.5

KNOWLEDGE & UNDERSTANDING

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



Excellent knowledge and understanding of the main concepts and key theories.

22.5

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, developed independently. Ability to investigate contradictory

22.5

information and identify reasons for contradictions.
Strong, persuasive, conclusions.

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, with extensive use of relevant examples. Creativity evident throughout.

14.8

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 with an exceptionally high level of professionalism. Work is exceptionally coherent, very fluent and is presented professionally.

8.1