EGB241 DC Motor Assignment

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Executive Summary

The intent of this report is to provide a scaled-down dc motor design proposition. Which could be scaled up to proportion to create a full-sized dc motor of the desired size with specifications that meet the tasks it could be assigned to. With there being many components required for designing a dc motor. It is important for there to be a way in which we can test out different values and options to allow the design to excel in specific areas. Entailed in this report are descriptions of MATLAB and an Excel document which aims to allow a designer to make adjustments to aspects of the motor such as the number of coils… Giving the ability for important design decisions to be tested before actually being prototyped. As the motor needs to meet the following given criteria:

- The motor must be DC powered and brushed/commutated.
- A minimum of 5 coils and Maximum of 8 are allowed.
- Only 45m of wire is permitted. Whilst the field must be provided by two permanent magnets from the provided sheet. Can assume the mass of the rotor is 0.5kgs.
- The motor cannot exceed 30V and 5A.

Additionally, the report covers recommendations for a technical reader looking to build the proposed prototype, by giving a risk analysis, demonstrating a potential way of approaching construction and looks into the financials of this project. The design must not only be able to run, but it must also be able to self-start without the need of an initial push.

Description

The proposed DC motor design is based on an 8 coil 2 pole lamination structure. 16 of these laminations are provided each at 1.2mm thick making the total length of the rotor 19.2mm. This provides for a 42mm^2 cross-section for the coils to fit in the slot. The winding configuration will be lap wound and should fit w coils per slot allowing for 16 coils in total with a wire gauge of 22 (AWG) giving a wire diameter of 1.024mm. In terms of voltage and current draw, the motor design meets the spec as it uses 5V and draws 4.05A of current as a maximum.

While the motor is operating under no-load conditions it reaches a maximum rotational speed of 2160rpm, whilst is maximum torque is at 0.04Nm. The mechanical power output is calculated to be 0.4watts with a degradation efficiency percentage of 20%. Theoretically, the system should be 20% efficient at those ratings. These are when the motor is being supplied 5v. They can be increased through an increase of voltage as long as it does not exceed the constructional limitations of the design, or the limits of the task. Since the speed of the motor is increased causing more vibrations and friction. The main sources of loss in the design will be friction and constructional limitations. A constructional constraint is the magnets used are straight cut meaning they cannot be well shaped around the commutator and rotor coils as some sections will have a greater air gap than others. To compensate for this getting them as close as possible around 1mm is ideal whilst using the strongest possible magnet. Both the windings and commutator experience friction therefore adding the resistance of the design making it less efficient. To help compensate for these a solid and strong construction of the casing holding the motor and magnets is essential as it will allow for the air gap to be as small as possible. In terms of friction ensuring good lubrication should allow for a minimal loss output.

The applications of such a design are crucial to the development of a larger scale possible industrial motor. Developing the design at a smaller scale allows for prototyping at a much cheaper price whilst providing the convenience of having a small device to tinker with and move around before actually scaling up the calculations and designing a full-scale prototype or even final design. This ultimately could save a potential company a lot of money and time.

The motor that will be designed in this report is targeted towards being high performing in the torque aspect. One of the main factors that influence a higher torque in the design is the magnet choice. It has the highest flux density per unit area in comparison to the other options. This allows for a maximum torque as the formula which calculates torque.

$$T_{ind} = k_2 * flux * I_a$$

Features the flux being multiplied therefore, is a factor that increases the torque. Higher flux means a higher torque.

Motor Calculations

Calculations have been done on both MATLAB and Excel to provide accurate simulations of how the motor will perform. These are useful as when it comes to build and prototyping the design selection of parts will be more tailored to the performance outcome that the motor is likely to achieve saving time and money. Excel makes it very easy to edit the figures and see how the motor could perform differently in various scenarios. Whilst MATLAB allows for simulations of the operation of the motor with time & torque. It allows for the extraction of data which is useful for judging how well the motor performs in real life under the typical loads it will be required to deal with. Any weak points or adjustments to the design can be made before any prototyping.

Excel

The excel portion of the calculations take in inputs and outputs the following final electromagnetic properties:

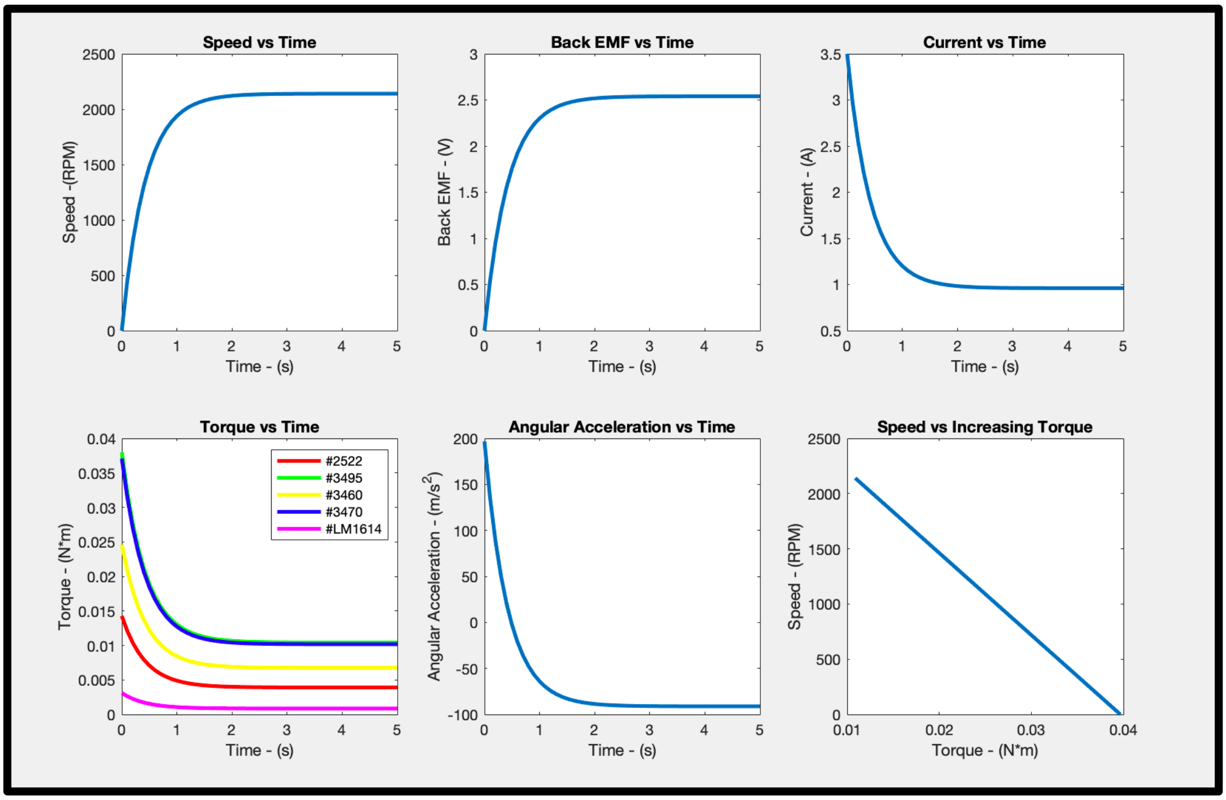
OUTPUT (Final Electromagnetic Properties)		
Parameter	**Value**	**Unit**
Maximum Rotational Speed ($\mathbf{n}_{r,max}$):	**2948.908061**	rpm
Rotational Speed at Max Torque ($\mathbf{n}_{r,fl}$):	**1753.53418**	rpm
Rotational Speed at Max Torque ($\mathbf{w}_{r,fl}$):	**183.6296699**	Rad/sec
Maximum Generated Torque ($\mathbf{T}_{max}$):	**0.029558731**	Nm
Maximum Produced Power ($\mathbf{P}_{max}$):	**5.427859959**	W
Motor may actually produce ($\mathbf{P}_{act}$):	**1.085571992**	W
Input Power ($\mathbf{P}_{in}$):	**9.128**	W
Efficiency:	**11.89%**	

These calculations have been conducted under no-load conditions. This implies that no friction or torque has been applied to the rotor. The motor is simply spinning freely. This is at 3.5v and a current of 2.608A due to the selection of 22 - (AWG) wire. The selection of this wire was due to its mid-range current usage and high torque output, leaving room for an extra current draw if needed. Furthermore, this design is based on an 8 slot armature design, which in comparison to a 6 slot design allows for more torque at the cost of a slower speed. However, this is the aim of the design so it acts in our favour. Additionally, to further improve the torque of the system. Selection of the #3495 magnet which is the strongest magnet per unit area. It allows for the highest torque output from the range which is similarly at the cost of speed.

MATLAB

The MATLAB simulations are as shown below. In this current configuration, the voltage is set to 3.5V with 0.02Nm of load torque applied. This acts as a frictional loss to simulate real conditions.

- Speed vs Time
  - This graph, located on the top left of the graphs below. It is a plot of the speed in RPM vs time. It shows that at just before 2 seconds the motor will reach its max speed of approximately 2100RPM. An increase of voltage here would increase the rpm however, the task requires it to run at 2000, so there is no need to overload to design.
- Current vs Time
  - As shown in the graph to the top right. The max current is 3.5 amps which is well below the 5A limit.
- Back EMF vs Time
  - This graph shows the motor will perform as expected, as it maxes out at 2.5v.
- Torque vs Time
  - This graph demonstrates the torque characteristics of the motor as time increases. Since it speeds up with time also it is expected that the torque will decrease over time. Since it is greater than zero when accounting for the frictional loads it means that the design is easily able to self-start.
- Angular Acceleration vs Time
  - This graph located at the bottom middle showcases the time it takes for the motor to speed up to max RPM. Which in this case is also approximately 2secs.
- Speed vs Increasing Torque
  - As expected in this graph to the bottom right. As the torque increases the speed will decrease. This can be increased by increasing the voltage, however, increasing it too much could burn out the brushes.



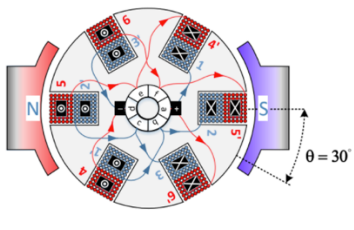
Recommendations

Design Strategy & Construction

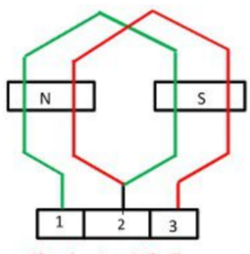
There are three main stages to the design of this dc motor. Overall assembly, testing, and final design. They should be implemented in that order to ensure that the construction of the motor is done appropriately, effectively, and minimises cost.

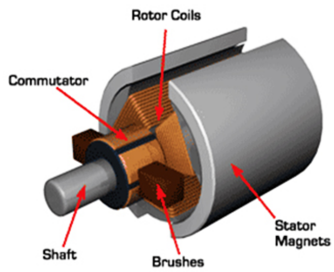
Concerning the assembly stage, this is one of the most important stages of the design. All the measurements should be exactly the right size as demonstrated in the construction diagram, or else there could be a high chance that a desirable air gap is not achieved due to vibration. The motor winding needs to have their slots insulated. As even though the copper used for the windings does have insulation around its outside to protect it. This can wear off due to rubbing with the lamination material. In accordance with (Basic Electrical Engg, 2001) which provides extensive recommendations for insulation material. Cotton/silk tape features good insulative properties whilst being quite thin, which is ideal for this scenario as we want to have as many winding as possible in each slot, not was space on insulative materials. This last step is optional to insulating however, some sources recommend to varnish the outside of the coils to further keep them well insulated in the armature. This design is lap wound and allows for 8 slots with 2 coils per slot. It should also features 40 turns per coil using up a total of around 41m of the 22 - (AWG) wire.

To properly lap wind the coils, the final setup should look like the 3 figures below. Although it is for a 6 slot setup. The 8 slot simplex design is very similar and the same design principles that go into the diagram below do apply to it. This is a stage that should not be rushed as the more well packed the windings the better. The goal is to fit as much copper as possible into the area provided by the slots.



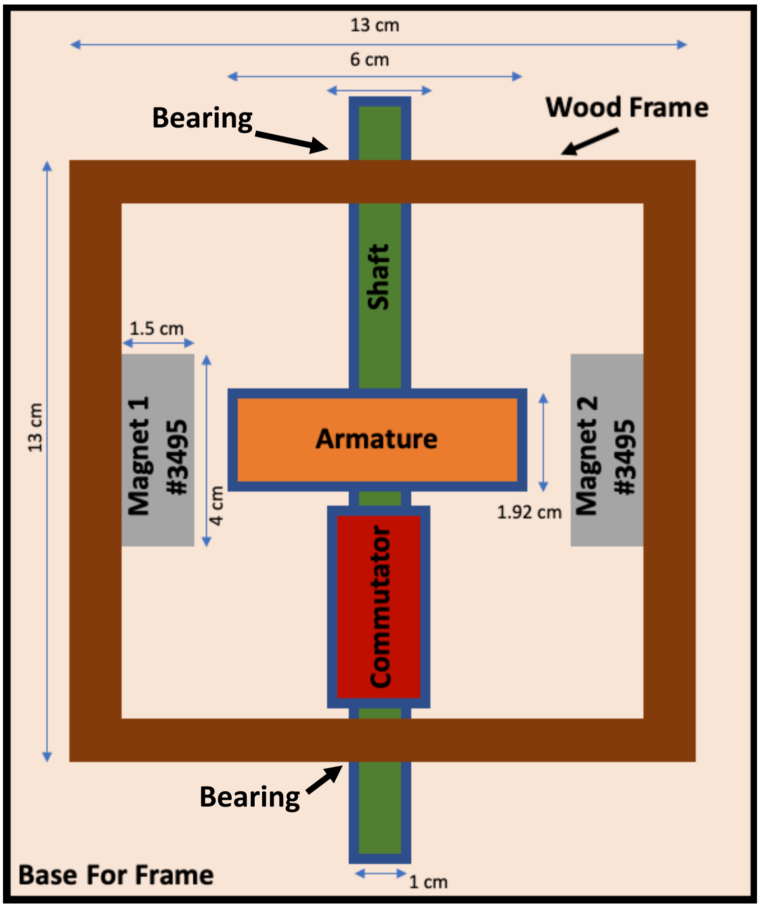
Current flow through coils at $\theta = 30°$



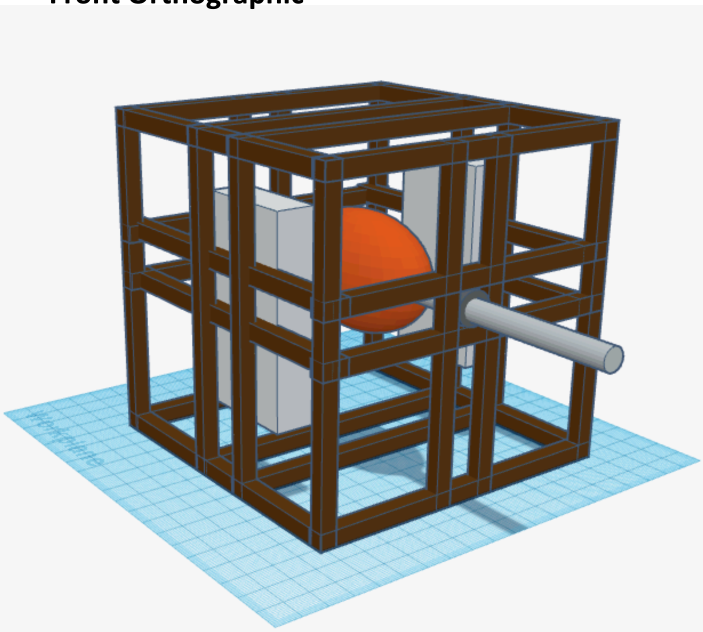


The next step of motor construction is testing, once it is assembled it is important to stick to the excel sheet and MATLAB specifications. As if not you run the risk of burning out the brushes and even breaking the design due to vibration if the construction material is not the strongest. Additionally, when testing select a voltage that allows the motor to meet the task specifications or a desired performance. As it assists with ensuring that the design is not being stressed more than it should be. The excel sheet can highly help with this. Once all the testing has been done to meet the requirements and comparisons of the real-life figures vs the calculated ones have been made. The design would have officially reached its final stage as it would have been tried and tested to the point of reliability and real world scalability.

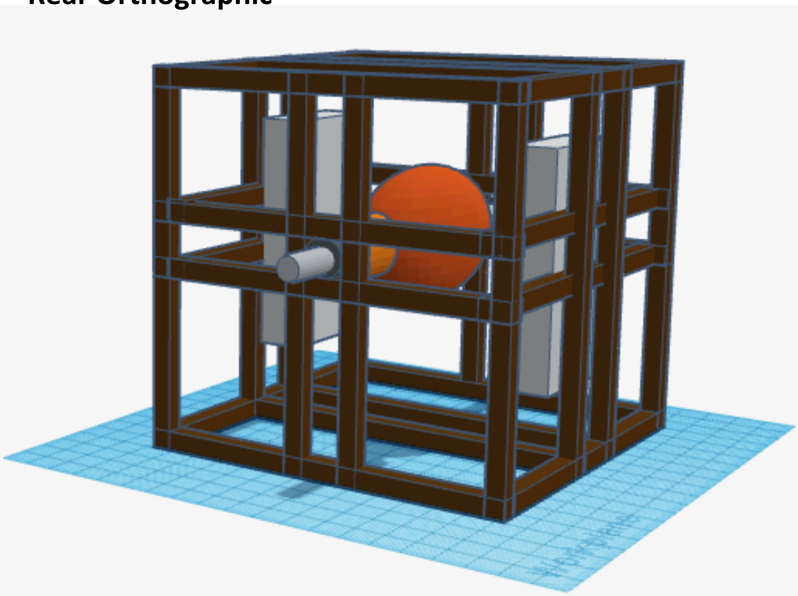
Construction Diagram



Front Orthographic



Rear Orthographic



3D model showing how the design could potentially look. It is a square (13x13x13)cm design allowing ease of construction. Having it easy to construct means that the design is harder to build wrong and will mean that the structure can perform at its best. Which in turn allows the airgap between the magnet and the armature to be as small as possible.

Construction Materials and Cost

All prices are sourced from different sources and averaged – (Are subject to change use this as a guide)

List of Parts			
Item	**Description**	**Quantity**	**Cost $**
Shaft	The shaft is what will be made to spin in the motor, This piece can be implemented to allow use of the mechanical output of the motor. It should at least be longer than the length of the laminations and commutator as shown in the image above.	1	10.00
Commutator & Brush	Essential for the operation of the motor.	1	8.00
Magnets #3495	Use of this magnet allows for the highest torque due to its density per area.	2	13.20
Copper Wire 45m 22 (AWG)	Essential for the operation of the motor.	1	5.00
Laminations	These should be 8 Coil laminations with dimensions as pictured below. Whilst being 1.2mm thick each.	16	3.00
Insulation – cotton tape	The gaps where the copper will sit in the laminations should be insulated.	1	3.00
Back iron – (optional)	This will act as a housing help to close off the magnetic path minimising flux leakage.	1	-
Structural Material	HDF wood is a strong rigid material that is cost effective for this construction.	1 – (sheet)	8.00
Ball Bearing	Allows for a low friction method for turning the shaft.	2	9.00
Lubricant	This will assist with minimising commutator flux leakage. Should be used on bearing.	1	5.00
Screws	Essential for holding the housing together.	-	5.00
Washers - Rubber	Essential of ensuring minimal vibration and a solid joint connection.	-	0.17
		Total:	69.40

These approximate prices are averaged from looking at multiple different online sources looking to sell individual components, or kit with multiples of these together all in one kit. In comparison to building a full-scale model costing around $69.40 is a very affordable solution under $100 to test the design out quickly and efficiently in any way desired. This gives room for a company to experiment with different solutions to the DC motor and try out different configurations.

Risk Analysis

Stages Key: Construction, Testing/Operation

Hazard	Description	How to Avoid
Burning out the Brushes	If the motor is overloaded it is easily possible to burn out the brushes due to the all the heat caused by friction.	To avoid this it is best to refer to the calculations in the excel and MATLAB file to see where the maximum performance of the dc motor is. These should not be exceeded without proper modifications to the design that allow it to compensate for the heat..
Vibration	Since the design features moving parts vibration is something that needs to be dealt with or else screws could come loose. Or the construction could weaken causing it to come apart and break.	To avoid this ensuring solid construction of the framing is essential. Adding rubber washers beneath the screwed joints could help minimise vibrations at the screws. Additionally, use of a strong material within the price range will highly benefit the solidity of the individual parts making them less likely to fail.
Spinning Parts	The Motor is designed to have a spinning shaft, therefore making it a moving object. This has the potential to inflict a lot of pain is you accidentally come in contact with the spinning part.	A way to avoid this is to ensure operation of the motor is only conducted when everyone in the area is aware of it operating. Additionally, use of safety lines or even strong gloves could minimise any possible contact.
Electricity	The DC powered motor has the potential to run on up to 30V at 5Amps. This could potentially cause harm to someone if directly contacting a part with flowing electricity.	This could be minimised in the final stage of construction by adding an outer shell to the parts which could be accidentally touched by someone.
Heat	Heat is one of the biggest risks in a project like this. It can be caused by overloading the motor and even just the normal operation causes heat due to friction at the commutator.	A way to avoid anyone coming into contact with heat is to ensure the motor is running at voltages and currents that have been checked by the calculations. Whilst the addition of a cover to parts that are hot would greatly assist with stopping accidental touches.

Conclusions

Future Improvements

In future, if redesigning this dc motor, looking into a more extensive range of magnet types could make it a better torque performer. Additionally, exploring results with possible different winding types other than lap winding could allow for a better torque performance than what the current design offers. On the flip side, if upon construction the materials used seem to be not rigid enough. It is recommended to explore stronger options to allow for minimal vibrations allowing for a small air gap. The current design has straight magnets which will lead to a lot of flux being leaked. To minimise this seeking a supplier that makes curved magnets, or finding a way to make them curved will make the prototyping a lot more expensive but it will give much better results. Another side where the motor can be improved is efficiency. It is currently only 11%, it would be much better if it can reach a higher value, through the use of better winding types and winding methods.

Conclusion

Overall, after the conduction of this design, it is apparent that a design that can at minimum rotate under its own generated force, has been designed. It is able to produce a high torque output of 0.015Nm assuming there is a slight fiction load of 0.02Nm. The simulations provide a strong building point for a reader potentially looking to construct and test this design to see how it will perform in the real world. All the instructions and key things to look out for have been covered in the risk management and Design/Construction Approach Section. These should give a potential building a strong insight into the budgeting and how to approach the construction of this machine.

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