School of Physics, Engineering and Technology

MEng Initial Project Report

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Project Title: Electric Vehicle Motor Design, Optimisation and Comparative Study

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Introduction

On top of my bookshelf back at home, there lies a relic from my childhood – a Mini 4WD toy car. Hopefully still running since the last time it got powered up, but once it is on the track the 4WD will just start flying. What drives the race car is the Tamiya Power-Dash motor, a fine piece of Japanese craftmanship. Powered by a pair of AA battery the Mini 4WD gain a lot of speed and torque to travel across the course with little effort, all of that is generated inside a motor of a size of a pebble. While it is surely a miracle in a tiny box, electric motor is no mystery to us in the current days.

Under the laws of Electromagnetism, an electric motor generates rotating force from the interaction of magnetic field of components inside the motor itself. The Tamiya motor from above for example, is a brushed DC motor that relies on powering the coils in the brush to create a flow of magnetic field, of which act along with the field of the permanent magnet (PM) on the side of the motor. This creates a perpendicular force on the coils (according to Fleming's left-hand rule) and with switching of pole at the commutator the motor achieves a constant rate of rotation.

Just like everything else, the bigger you go, the more you get out from it. While you can surely push a toy forward with a coin-size motor, electric motors are also used to provide power to all kinds of machineries, from household appliances to industrial instruments. Out of all the applications however, one area has advanced significantly during the recent years. The automotive industry is currently in the trend of electrification. With more efficient and better preforming electric motor technology being developed, the more environmentally friendly source of power has led to an explosion of hybrid and electric vehicle(EV) in the global market.

You may imagine that the development of such technology requires a broad range of expertise. While you may need some fundamental knowledge of electromagnets, the structural design and verification of a design is nothing impossible to anyone with the modern computational power. Computer-aided Design (CAD) is now a universal design technique in many areas, using software to draw model of design and simulate the behaviour of the design. The use of CAD dramatically speeds up the development process and reduce the cost needed to constantly produce physical prototype for testing.

In this project we will be demonstrate the design and optimisation of EV motor and investigate the structure of EV motor using CAD software, proving the capability of such technique.

Specification

The Aim of this project:

1. To understand the principle of EV motor infrastructure.
2. To introduce the use of CAD (CAD) software for electric motor design.
3. To introduce the use of Finite Element Analysis (FEA) to simulate the designed model.
4. To introduce the use of optimisation tool to optimise parameter of a design.
5. To analyse the relationships between motor parameters and the torque of the motor.

The Objective of this project:

1. Design electric motor according to a specification with aid of modelling software.
2. Model the designed motor to obtain its electromagnetic characteristics.
3. Present the result of the motor graphically with aid of mathematical software.
4. Sweep parameter of the model to visualise the design space of the motor.
5. Use the optimisation tool to produce parameter optimised designs.
6. Compare the performance of the designs rationally and justify the reliability of the optimisation tool.
7. Sweep parameters of motor to unveil the relationship between each parameter and the torque of the motor.

The target platform for the project is to be on the COMSOL Multiphysics 6.0

Overview

First and for most, the focus of this project is to introduce the method of CAD alongside with FEA rather than the detailed mathematical deduction of a theoretical rotary design of electric motor. While the theory is curial to the project, the matter of electrical rotating machinery has been well studied for decades. Published by the Institute of Physics, "Electromechanical Machinery Theory and Performance" [1] have an excellent explanation to the theory of electromagnetic machine, including a whole chapter dedicated to AC rotating machines. While creating a design from theory will undoubtfully converge to the same result, the time and effort in comparison however falls to the intelligent side of the matter. Furthermore, by designing digitally it is much easier to spot and correct problems in the design.

Abstracting from the well written textbook by Thomas A. Lipo [2], the structure of electric machine design can be divided into 5 sectors: Electric, Magnetic, Dielectric, Thermal, Mechanical. The first item defines the powering of the machine, the next couple controls the magnetic behaviour inside the device, and the last two parts specify its physical properties in action. While one may have great understanding in a specific area, it is unlikely that a person would have specialised himself in all the related field. This is where modelling software comes into play, providing an effortless way to gain extensive information from a partial design of the target product. The use of software reduces the demand of knowledge required for each engineer, encouraging a larger population to enter the technology field.

Back to the topic of motor, the main types of electric motor in the current industry are the Induction motor (IM), the Permanent Magnet Motor (PMM), and recently the latest Synchronous Reluctance Motor (SynRM). Research [3] shows that while SynRM has the best performance of all and IM are best known with its cost and reliability, the PMM is the most popular choice as being well established and top notch in speed and power efficiency. Between the two types of PMM, the Interior Permanent Magnet (IPM) motors is more common used for EV than its opposing Surface-mounted Permanent Magnet (SPM) motors with less demand in the magnetic material. As such, this project is going to work with the IPM motor infrastructure specifically.

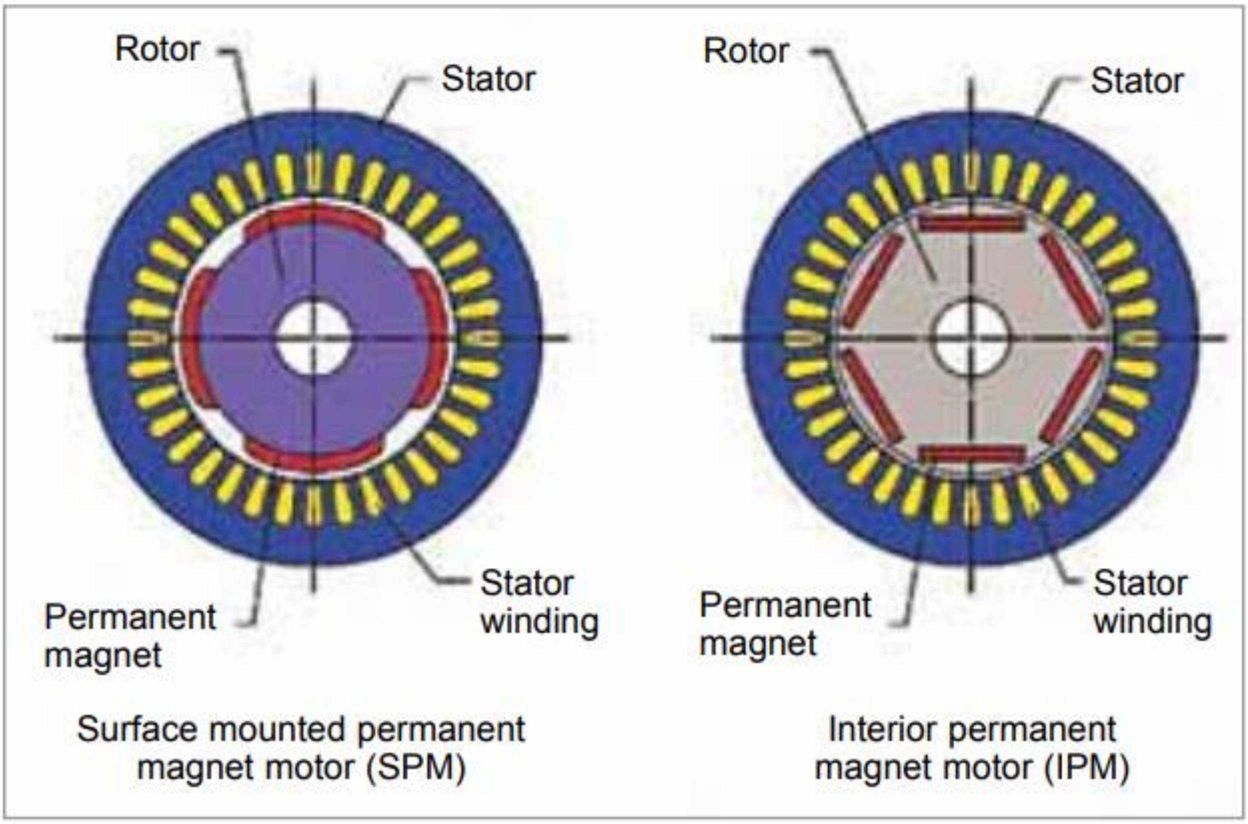


Figure 1 Cross-section of SPM and IPM motor design [4]

There are a huge range of choice on CAD software available in the market, for the automotive industry CATIA, Creo and Siemens NX is the common choice. To hobbyist and student though this software might simply be unaffordable and difficult to obtain. One of the alterative for a more friendly choice is the Ansys Motor-CAD, for student Ansys also provide the free Ansys Electronics Desktop for basic development. However, for this project the student version is just not capable to perform the task required later on the project after test by myself. The target software is decided to be the COMSOL Multiphysics after obtaining a license from the supporting member of the project. Upside of the COMSOL software is its library of common mechanical model for quick and easy design of device. IPM type of rotor is also available which is very convenience for the project. Furthermore, the COMSOL improved FEA system Multiphysics provide more flexibility to the design for integrating different physics system to the same model.

Many research has been made on CAD modelling for EV motor, mostly related to other types of motor such as the Switched Reluctance Motor(SRM) [5] and IM [6] structure. The only Multiphysics design approach [7] found for IPM motor is a more general overview of the aim of this project, however this project is more and only interested in the torque performance of the IPM motor and how each design element may have an effect to the performance of the motor. On the modelling side, COMSOL has released a full guide on modelling a SPM motor with the software. This can be use as a guide of the modelling of the IPM motor but from some testing difference can already be spotting and will have to proceed with precaution rather than blindly following.

Description

To achieve the stated specification, this project is to be staged into 6 sections, being as follow:

1. Study Stage

   This stage is where the basic principle of EV motor design is being researched and understood.

   i. Research on the general AC motor design methodology.
   ii. Research on the use of Maxwell's equation in motor design.
   iii. Research on the IPM motor infrastructure.

   This stage is supposed to happen before and through out the period of the project. Additional research might be needed, and such shall be appended to the list of item for this stage. This stage should have a low risk with plenty of knowledge accessible through the internet,

2. Design Stage

   The target of this stage is to demonstrate the model generation function in COMSOL.

   i. Draft an initial specification of the IPM motor on the diameters and features of the IPM motor.
   ii. Draw 2D model of the IPM motor with the aid of COMSOL AC/DC module according to the specification.
   iii. Assign material to each part of the model accordingly.
   iv. related physical components to each part of the model accordingly.

   This should require minimum effort once the specification is made and should have a low risk to the project.

3. Simulation Stage

   This stage is aimed to demonstrate the tool ability in simulating the behaviour of the model running overtime and be able to display the result in a graphical format.

   i. Run stationary simulation to obtain the distribution of magnetic flux in the design graphically.
   ii. Run transient simulation to obtain the torque of the motor model at a specific

rpm.

Obtaining the torque may require more care in the matter due to lack of relevant experience, but not undoable, rating the stage at medium risk overall.

4. Optimisation Stage

This stage shall demonstrate the parameter sweeping and optimisation study modules in COSMOL.

i. Run parameter sweep on design against the torque produced at specific rpm.
ii. Run parameter optimisation on design to optimise one of the design parameters to generate the most torque at the staff.

The major concern here is the optimisation tool which with little knowledge in CAD design may required more time to get through. This part can be seen as the bottleneck of the project thus is likely to be at high risk.

5. Comparison Stage

This stage shall show how to compare the optimised design to the original design, and finally discuss on the performance of the optimisation module in COMSOL.

i. Repeat stage 3 with the optimised design.
ii. Compare the performance between the original and optimised design.
iii. Justify if the optimised design agrees with the result of the parameter sweep at stage 3.

This stage is at low risk on its own but greatly depend on the success of the previous stages.

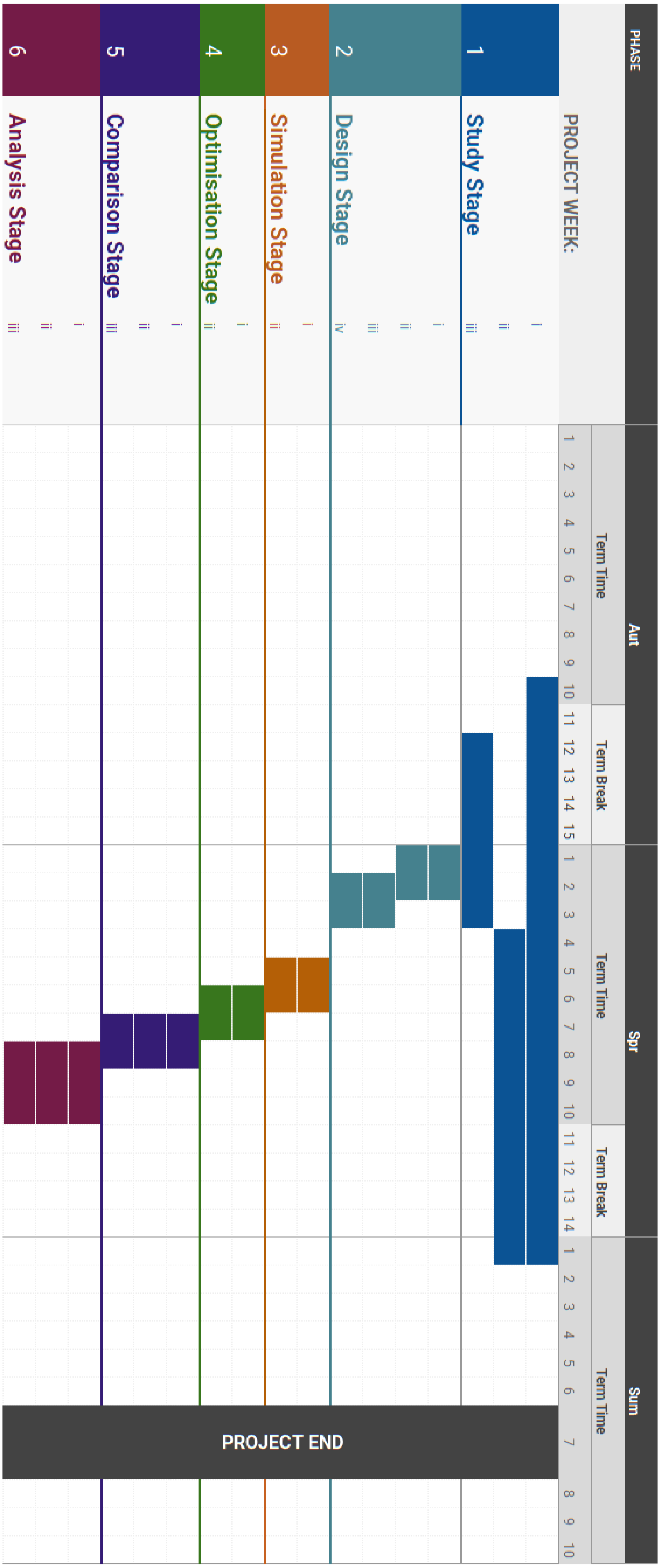
6. Analysis Stage

This stage will analyse the relationship between each parameter and torque generated of the motor.

i. Sweep each parameter of the motor.
ii. Analyse the effect of each parameter to the change of torque of the motor.
iii. Derive a relationship from the analysis, mathematically if possible.

Sweeping and analyse all parameter requires significant amount of time which set the task at medium risk.

Timetable


PHASE
PROJECT WEEK:
Aut
Spr
Sum
Term Time
Term Break
1 Study Stage
2 Design Stage
3 Simulation Stage
4 Optimisation Stage
5 Comparison Stage
6 Analysis Stage
PROJECT END

References

[1] T. Ortmeyer, Electromechanical Machinery Theory and Performance, Philadelphia, US: IOP Publishing, 2018.

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[4] J. Ahmad, “Selecting The Right Motor For Your Design,” *Electronics For You,* vol. 53, pp. 56-61, 2021.

[5] F. L. M. d. Santos, J. Anthonis, F. Naclerio, J. J. C. Gyselinck, H. V. d. Auweraer and L. C. S. Góes, “Multiphysics NVH Modeling: Simulation of a Switched Reluctance Motor for an Electric Vehicle,” *IEEE Transactions on Industrial Electronics,* vol. 61, no. 1, pp. 469-476, 2014.

[6] V. B. Aguiar, R. S. T. Pontes and T. R. F. Neto, “Study and energy efficiency improvement in the design of an induction motor based on interactive CAD software,” in *Brazilian Power Electronics Conference*, Gramado, 2013.

[7] P. Akiki, “Multiphysics Design of a V-Shape IPM Motor,” *IEEE Transactions on Energy Conversion,* vol. 33, no. 3, pp. 1141-1153, 2018.