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at the University of Windsor

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# ABSTRACT

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NOTES:

1. Look at troubleshooting documents on desktop and in uwindsor drive as supporting visualizations

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# CHAPTER 1 Induction Motor Theory

## *Converting electrical energy to mechanical energy*

### *Motor Characteristics*

Mmf =ʃ H.dl, while V = Emf = ʃ E.dl

Talk about the diffusion equation and the magnetic vector potential which is approximately related to the B field

I NEED TO FIND AIDAS PAPER SHE SENT ME THAT EXPLAINED THE APPROXIMATION OF THE MAGNETIC VECTOR POTENTIAL AND QUASI STATIC APPROXIMATION

Text

Description automatically generated with medium confidence

* Convert electrical energy to mechanical energy

The purpose of an electric motor is to transform the electrical energy input into mechanical energy, since they are mutually convertible, by utilizing the principle of induction. When a magnetic field is applied to magnetizable bodies, magnetic flux concentrates throughout the newly magnetized material. This concept is elegantly explained through Ampere’s Law stating that magnetic field strength is strongest when the closed path of magnetic field lines is minimized.

Word

Description automatically generated with medium confidence

Magnetic reluctance is an important material property which quantifies the resistance to a change in magnetic field. The geometry and the permeability of the material directly affect its reluctance. A path of least resistance is produced when the overall reluctance and path length are minimized.

In motor design there are options in the way that the magnetic field is produced which materializes in the form of magnets and current-carrying conductors. Magnets will produce a relatively constant magnetic field that is useful for its magnetization density. Additionally, magnets can operate without reliance on an external source since the magnetic field is produced inherently through the alignment of electron spin throughout the material. Alternately, current carrying conductors produce magnetic field with closed field lines around them. These conductors can be organized into coils and placed in crucial locations throughout a motor to maximize the magnetic field produced.

With the concepts of flux and reluctance defined, magnetomotive force is used to quantify the ability to produce flux. The magnetic circuit model is useful in explaining the behaviour of magnetic field in a material. It is analogous to the electric circuit which defines charge flowing because of a voltage potential through a resistive material. In the magnetic circuit, flux is a consequence of an MMF potential across a source like current carrying conductors in a motor. The flux is resisted through the magnetic reluctance of materials like resistivity in electric circuits. Although the strategic approach of modelling magnetic circuits like electric circuits simplifies the motor modelling, there are important differences.

* AC Motors vs DC motors
* Linear vs rotary
  + Joule loss by the eddy current in secondary conducting plate
* Asynchronous vs synchronous
  + Asynchronous means that the synchronous speed and mechanical speed are different due to a slip. [link](https://circuitglobe.com/difference-between-synchronous-and-asynchronous-motor.html#:~:text=and%20Asynchronous%20Motor-,Synchronous%20motor%20is%20a%20machine%20whose%20rotor%20speed%20and%20the,less%20than%20the%20synchronous%20speed.&text=Synchronous%20motor%20does%20not%20have%20slip.)
* Multiphase vs single phase windings
  + SWISS s2.2.3

### *Asynchronous multi-phase linear induction motors*

* Motor types that are filtered by linear, AC, asynchronous, multiphase
* Design Parameters of a linear induction motor [link](https://www.linearmotiontips.com/what-are-linear-induction-motors/)
  + Focus on important ones for code, ex) slots, poles, any ratios in geometry
* Performance Parameters and basic equations
  + Christopher Timperio [link](https://www.research-collection.ethz.ch/handle/20.500.11850/379531)
  + Airgap importance
  + Carters Coefficient
* Motor Losses
  + <Although asynch SSLIMs do not experience mechanical do to not needing a gearbox or similar drivetrains>
  + End effects
  + Edge effects
  + Thermal effects
  + Material Loss
  + Search up more
  + Saturation (we can use HAM to check B field based on MEC density)
  + NOTE: I should follow a rule that in this saturation section above I am mentioning it because I can talk about it as a use case of my code. I think I should write a short mention up here that this is important because it will be mentioned later

### *Design Considerations*

* Design Considerations (only things applying to the ratios and python model itself)
  + Geometry limitations that create feasible designs

# CHAPTER 2 Modelling Techniques

## *Industry Standard*

### *Field Modelling*

* Industry Standard (use my powerpoint where I surveyed the industry)
  + MEC vs HM vs ECM vs FEA

The equivalent circuit model [ECM] is the least computationally intensive modelling technique due to model being approached semi-analytically. Coupling resulting data from a finite element analysis [FEA] simulation or lab testing with the ECM can produce accurate results describing the characteristics of a motor while removing the need to simulate an FEA model. Additionally, some characteristics of a motor are difficult to acquire in a lab setting due to limited resources and can be more efficient to simulate. The energy transfer between the stator and rotor of a motor is like a transformer equivalent circuit which models the energy transfer from primary to secondary windings.

Include a picture of a circuit model [link](https://www.electricaldeck.com/2020/11/equivalent-circuit-of-induction-motor.html#:~:text=The%20equivalent%20circuit%20of%20an,characteristics%20of%20the%20induction%20motor.)

While many of the circuit component values are easy to deduce such as primary resistance and current, reactance, especially in the secondary, can be difficult to measure and often introduces error.

While the ECM was very computationally efficient, FEA is the opposite. It is a mesh-based simulation that divides the entire model into polygons in its pre-processing process. The boundaries between polygons and the discontinuous border conditions create a set of equations that can be solved. The solution is then applied to the mesh to produce the post-processed result which provides unique model characteristics inside each polygon. This technique is very commonly used in many fields which require computational modelling. The accuracy of the simulation is proportional to the density of the meshing in the geometry. Logically there is computation time and space complexity which is traded for accuracy due to the size of the computations required for the matrix solution. For this reason, FEA simulations of motors are run at low mesh densities until a final design is ready for finalized characterization.

Magnetic equivalent circuit [MEC] modelling is a subcategory of FEA specific to magnetic circuit modelling. MEC is commonly used in custom modelling methods due to its flexibility and simplicity. The model works on a conservation of flux principle stating that the amount of flux entering a polygon must also exit the polygon. Since MEC is a subcategory of FEA it is burdened by large computation requirements and is only useful for niche modelling applications where industry FEA applications are not applicable.

SHOW THE NODAL model like the neighbouring nodes diagram in 2019

Harmonic modelling is a technique used to approximate waveforms using Fourier analysis. The approximation of the waveform is in the form of a summation of N harmonics, where n is the current harmonic number. Each harmonic has its own unknown variables that need to be solved in the matrix equation. The harmonics count is what defines computations

SHOW THE FOURIER EQUATIONS

* + Motor optimization

### *Model/Motor Optimization*

## *Hybrid Analytical Modelling*

I have not yet talked about how MEC mesh extends the whole x and y direction meaning that a very simple geometry will be made intensive by a complex neighbouring geometry which is a perfect use case for hybrid modelling

### *MEC*

* MEC (talk about benefits as well as explain it)
  + Complex geometries or even geometries that are not constant in the periodic direction
  + Discretized EM field behaviour
  + Nodal analyses and conservation of flux

### *Harmonic Modelling*

* HM (talk about benefits as well as explain it)
  + Fourier series and harmonic modelling
  + Much simpler math
  + Scales with number of harmonics not space (mesh density)
  + Periodic direction

### *Genetic Algorithm*

* Motor Optimization
  + Optimization algorithms
  + Are there other types?

# CHAPTER 3 Model Structure

## *Pre-Process*

### *Build Motor*

### *Build Grid*

### *Compute HAM*

## *Post-Process*

### *Update Grid*

### *LIM\_Show*

### *Platypus*

* Python function for checking model integrity
* (provide the link of the module?)

# CHAPTER 4 Proof of Results

## *Compare to FEA*

### *Sub-Section Heading Here*

* Compare to FEA
  + Multiple sims with results of
    - B field in core
    - B field in airgap
    - Thrust plots
  + Magnetostatic vs Transient
* Error
  + Quantization
  + Lu decomp
  + Fourier harmonic number (approximation of the waveform)
  + MEC discretization error
  + Assumptions made in math in the 2019 paper (top of page)

## *Convergance of GA towards improvement*

### *Multi-Objective Function % Improvement*

### *Pareto Front or “Objective Normalization”*

* Convergance to improvement for GA

# CHAPTER 5 Computation Considerations

## *Section Heading Here*

### *Sub-Section Heading Here*

* MEC and HM scale in computation time through mesh and harmonics
* Efficiency
  + Memory
  + Time Complexity
* Hyperparameter Optimization
* Computer Hardware Considerations
* Multiprocess/Coroutine
* Caching
* Class Inheritance

# REFERENCES/BIBLIOGRAPHY

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# APPENDICES

## Appendix A

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# VITA AUCTORIS

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|  |  |
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