The University Of Sheffield.

Electronic & Electrical Engineering.

EEE350 ELECTROMAGNETIC FIELDS ANS DEVICES

Credits: 20

Course Description including Aims

The aims are:

1. To develop an understanding of the physical behaviour of electric and magnetic fields.
2. To develop a mathematical basis for calculating electric and magnetic fields in engineering applications using analytical methods.
3. To apply these ideas to solve practical problems with a particular focus on electrical power applications.
4. To introduce students to numerical methods for calculating fields, including practical experience in using a commercial package for solving power engineering problems.
5. To develop an understanding of the relationship between dimensions and rating of machines.
6. To introduce the principles of winding designs.
7. To develop techniques for the design of permanent magnet machines.
8. To calculate representative winding reactances.

Outline Syllabus

Review: vector quantities and operations. **Static fields**: electric and magnetic fields. **Maxwell's Equations**: introduction, application to electrostatic fields, application to magnetostatic fields. **Low frequency time-varying fields**. **Numerical methods**: calculating magnetic fields. **Magnetic field calculations in rotating electrical machines**. **Machine Ratings :** leading dimension of machines, electric and magnetic loadings, thermal design considerations. **Windings :** types of windings, their design, choice of winding arrangements, harmonic effects. winding reactances. **Permanent Magnets :** types of magnet, analysis and design of PM devices, design of permanent magnet machines.

Time Allocation

48 lectures plus 24 hours of additional support material.
3 hour introductory computer laboratory session for FEMM software
12 hours of timetabled computer laboratory drop-in sessions to assist with FEMM assignment – supported by demonstrators

Recommended Previous Courses

EEE223, MAS241

Assessment

3 Hour examination, answer 4 questions from 6.
Individual assignment on using the FEMM finite element package to solve one electrostatic and one magnetostatic problem. This will be assessed by submission of a written report detailing results obtained and a 10 minute viva voce examination to explore understanding of the processes involved in the modelling (accounts for 25% of the final grade)

Recommended Books

Say, M.G.	*Alternating Current Machines*	(McGraw-Hill)
Miller, T.J.E.	*Brushless Permanent-Magnet and Reluctance Motor Drives*	(Oxford Science)
Hendershot, J.R.& Miller, T.J.E.	*Design of Brushless Permanent Magnet Motors*	(Oxford Science)
Kenjo, T.	*Permanent Magnet and Brushless DC Motors*	(Oxford Science)
Lipo, T.A.	*Introduction to AC machine design*	(Univ of Wisconsin)
Hammond, P.	*Electromagnetism for engineers*	Pergamon Press
Cheng, D.K.	*Field and wave electromagnetics*	Addison-Wesley
Demarest, K.R.	*Engineering Electromagnetics*	Prentice Hall
Hayt, W.H.	*Engineering Electromagnetics*	McGraw-Hill
Kraus J.D	*Electromagnetics*	McGraw-Hill

Objectives

On completion of the module successful students will be able to

1. perform a range of vector operations.
2. select and apply appropriate analytical techniques for calculating electrostatic or magnetic fields in a range of practical devices.
3. identify and specify approximate models and boundary conditions for a range of devices.
4. use a finite element package to solve 2D electrostatic and magnetostatic problems in practical electrical power devices
5. appreciate the link between electromagnetic field calculations and the features and design of practical power engineering components, devices and industrial processes.
6. Calculate the leading dimensions of a machine subject to the specified design constraints.
7. Develop winding layouts and calculate the harmonic content of their mmf or of the emf induced in the windings by a rotating field.
8. Suggest the choice of an appropriate permanent magnet material and its main dimensions when used in an electric machine.
9. Develop the skill for magnetic circuit analysis of permanent magnet machines, including working point, airgap flux density, maximum energy product, demagnetisation withstand and temperature effect.
10. Calculate the reactance of a winding or components of the reactance from the dimensions of a machine and relate these to equivalent circuit models developed in earlier years of the course.

Detailed Syllabus

- Outline of course contents, rationale of the course,
- **Review of key vector techniques :** Coordinate Systems, Review of vector representation of field quantities; concepts of flux and field strength, principle of superposition, scalar and vector product, line and surface integrals, gradient operator and divergence operator.
- **Introduction to static electric fields:** Key physical quantities, Coulomb's Law, electric fields and electric potential, physics electrical breakdown, behaviour of dielectric materials.
- **Introduction to static magnetic fields:** Key physical quantities, Biot-Savart Law, Ampere's Law.
- **Introduction to Maxwell's equations:** Mathematical basis and key features, simplifications for static and power frequency problems
- **Application of Maxwell's equations to electrostatic fields:** Gauss's theorem, Laplace's equation, Poisson's equation; Analytical methods for calculating fields, application to parallel plate capacitors, high voltage transmission lines and cables. Practical aspects of high voltage cables.
- **Application of Maxwell's equations to magnetostatic fields:** Ampère's law, Stokes' theorem, scalar and vector magnetic potentials, boundary conditions, calculation of static fields in simplified geometries such as MAGLEV transportation system.
- **Low frequency time-varying fields:** Faraday's law, diffusion equation, skin depth, 1-D eddy current in thick and thin plates, AC resistance, proximity effects, application to induction heating.
- **Numerical methods for calculating magnetic fields:** Basic theory of finite element analysis, boundary conditions, periodicity, force calculation, examples of application to engineering problems using commercial FE package.
- **Finite element assignment:** Introduction to FEMM finite element package and the use of FEMM to solve one electrostatic and one magnetostatic problem.
- **Machine specification:** An overview of and limiting technologies, examples of computer-aided-design.
- **General output equation:** Development of general output equations, relating dimensions to output torque and electric and magnetic loadings.
- **Material properties:** Discussion of the limiting material properties and operational conditions on the output power.

- **Specific motor topologies:** Application of the output equation to specific motor topologies, design objectives and motor types.
- **EMF equation:** Development of the general emf equation for an ac winding taking account of coil span, winding distribution and skew. Calculation of harmonic winding factors.
- **Induced emf:** due to a non-sinusoidal rotating field. Harmonic content of practical windings. Resultant space and time harmonic fields for single and three-phase windings.
- **Three phase winding layouts:** winding phase vectors, winding factors.
- **Permanent magnets:** typical B/H characteristics, important properties, nomenclature and definition. Equivalent circuit models, working points, graphical interpretation and critical design objectives. Analytical models of magnet behaviour, calculation of open circuit flux density and demagnetisation conditions. Magnet recoil operation. Calculation of magnet dimensions for specific operational conditions, minimum magnet volume conditions.
- **Permanent magnet machines:** Application of magnets in permanent-magnet machines and machine topologies. Review of equivalent circuit models for dc and ac machines. Calculation of air-gap fields and winding reactance for concentrated and distributed windings. Relationship to main magnetic circuit dimensions. Calculation of magnetising reactance and major components of leakage reactance in machines.

UK-SPEC/IET Learning Outcomes

Outcome Code	**Supporting Statement**
SM1p	The theories of electromagnetics, energy conversion, magnetic circuit, properties of materials and loss mechanism are uniquely combined in this module, with close relation to engineering application, such as the influence, analysis and minimisation techniques of harmonics in both magnetomotive force (mmf), electromotive force (emf), and winding inductances are comprehensively discussed, together with their relation to electrical machine designs. The students will be able to demonstrate the ability to design modern electrical machines and their knowledge will be tested in the examination.
SM1m	Students will be able to understand and analyse the phenomena of parasitic effects such as cogging torque and leakage flux, etc. in electrical machines in order to reach a good design for different engineering applications. Thorough grounding in the scientific principles of electric and magnetic field and the means by which these principles underpin many engineering devices. Assessed in both written examination and in FEA assignment.
SM2p	The application of mathematical tools to engineering problems, from field harmonic analysis, magnetic circuit analysis, to derive the relationship between machine size and design parameters, is a fundamental aspect of electrical machine design. This is tested in the examination.
SM2m	Extensive exposure to, and practice in the use of, advanced mathematical techniques – primarily focussed on vector calculus. Assessed by way of problem solving and derivation in written examination
SM3p/SM3m	The machine design is multi-disciplinary, including electromagnetics, mechanics, thermal management, computer-aided design, . These are fully integrated in the course and tested in the examination.
SM4m	The application of various electrical machines to different market sectors, ranging from domestic appliances, wind power generators, to electric vehicles, is emphasized, and special considerations of machine design in order to suit for a specific application are fully aware of.
SM5m	Linear analytical models are employed throughout the course, but their limitations due to material nonlinearity lead to the necessity of numerical

analysis such as finite element analysis or approximation in the analysis. Such skills are key techniques for machine design. Tested in examination.

SM6m Skilfully applying the multi-disciplinary knowledge is a key to good machine design. This is particularly emphasized in the course.

EA1p The essence of this module is to apply basic knowledge, including electromagnetics, energy conversion, magnetic circuit, properties of materials and loss mechanism, to derive the relationship between dimensions and output torque and power, to analysis the harmonic effect, losses and demagnetisation withstand etc. It is tested in the examination.

EA1m The basics relating to electromagnetics, mechanics and thermal management have been comprehensively introduced. Students are expected to use those taught basics to analyse the performance of electrical machines for specific industrial applications. This will be tested in the examination.

Extensive practical activities in using FE analysis for solving a range of problems. Assessed by way of FEA assignment.

EA2p Analytical analysis and modelling techniques are required throughout this module and subsequently used in the performance analysis. This is tested in the examination.

EA2m Different analytical methods relating to the calculation of EMF, output torque, iron losses and winding inductances are introduced throughout this module. Students will master those skills and be able to analyse the performance of a designed machine. This will be tested in the examination.

EA3p Due to non-linear phenomena in the magnetic circuit and harmonic effect, numerical method is often required, while the complexity of the subject requires necessary approximation.

EA3m Various numerical methods and practical engineering techniques are taught in the module, together with their merits and demerits.

Application of both analytical and numerical methods to predict aspects of performance of many devices which exploit electric and magnetic fields. Comparison of advantages and disadvantages of the two types of methods in some cases by direct comparison of results produced by both types of methods. Assessed in both written examination and in FEA assignment. In the case of the latter, questions posed in comparing performance derived from ideal scaling and numerical solutions which include saturation.

EA5m The students are required to demonstrate the ability of analysing the new machine topologies.

D1p / D1m For different application, the emphasis of machine design may be on the cost, reliability, torque/power density, or other performance according to the customers, which will lead to different machine designs, as shown by examples in the module.

Students are taught to use assumptions due to the complex nature of machine design, and they are aware of different assumption might lead to different final design of electrical machines. Apart from analytical modelling, students are taught that the sophisticated numerical modelling could effectively mitigate the inaccuracy introduced due to assumption in analytical modelling.

D2p /D2m Electrical machines are always required to be designed to suit for a specific application with special constraints. This is tested in the examination.

The theories relating to electromagnetics are comprehensively introduced throughout this module, students will be able to use those theories to analyse the

	performance of new machine topologies. This will be tested in the examination.
D3p / D3m	Students are taught to use assumptions due to the complex nature of machine design, and they are aware of different assumption might lead to different final design of electrical machines. Apart from analytical modelling, students are taught that the sophisticated numerical modelling could effectively mitigate the inaccuracy introduced due to assumption in analytical modelling.
D5i	The students are aware of the fact that the machine design is mainly about the balance between the cost and performance. This has been emphasized throughout the module.
EP1p / EP1m	Students are taught that any development in new materials, such as rare-earth magnets, superconductors, new insulation materials, or modelling techniques will be reflected in the machine design.
EP2p / EP2m	Students are taught the characteristics of various soft and hard materials (e.g. copper, iron laminations and permanent magnets), loss mechanism, property variations according to different operating environments and cost implications. Such skill is tested in the examination.
EP6p, **EP6m**	The students are taught to be aware of test and industrial standards**.**
EP9m	Students are taught the techniques how to utilise the advantages and overcome the disadvantages of various soft and hard materials, as well as new emerging materials, in developing new machine topologies and improve the machine performance.
EP10m	The module emphasizes that the machine always needs to be designed under cost and environment constraints for domestic, vehicle and aerospace applications. Students are taught how to consider these into the practical design, as tested in the examination.
ET2fl	The students are aware of the fact that the cost and environmental impact of different materials will have a significant impact on their machine design.
ET4fl	The students are aware of the fact that the cost and environmental impact of different materials will have a significant impact on their machine design.
ET5fl	The students are taught to be aware of the test and industrial standards.