The University Of Sheffield.

Electronic & Electrical Engineering.

EEE6204 PERMANENT MAGNET MACHINES AND ACTUATORS

Credits: 15

Course Description including Aims

The aims are:

1. To develop an understanding of the relationship between dimensions and rating of machines.
2. To develop techniques for the design of permanent magnet machines.
3. To introduce the topologies of different permanent magnet machines and actuators.
4. To develop an understanding of the relationship between power losses and thermal management.
5. To introduce winding arrangement and calculate representative winding reactances.

Outline Syllabus

Machine Ratings: leading dimension of machines, electric and magnetic loadings, thermal design considerations. **Windings:** special types of windings for permanent magnet machines, their design, choice of winding arrangements, harmonic effects, winding reactance. **Permanent Magnets:** types of magnet, magnetic circuit, demagnetization, analysis and design of PM devices. **Machine and actuator topologies**: electromagnetic torques, Brushless AC/DC, fractional slot, switched/transvers flux permanent magnet machines, etc. **Thermal management**: types of losses, thermal phenomena, thermal modeling using lumped parameter and finite element.

Time Allocation

36 lectures plus 12 hours of additional support material.

Recommended Previous Courses

Students should have background knowledge equivalent to EEE223 “Energy Management and Conversion”

Assessment

3-hour examination, answer 4 questions from 6.

Recommended Books

Hanselman, D.C.	Brushless Permanent-Magnet Motor Design	(McGraw-Hill)
Hendershot, J.R.& Miller, T.J.E.	Design of Brushless Permanent Magnet Motors	(Oxford Science)
Pyrhonen, J., Jokinen, T, & Hrabovcova, V.	Design of Rotating Electrical Machines	(John Wiley)
Lipo, T.A.	Introduction to AC machine design	(Univ of Wisconsin)
Gireas, J., & Wing,	Permanent Magnet Motor Technology	(Marcel Dekker)

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Objectives

On completion of the module successful students will be able to

1. Calculate the leading dimensions of a machine subject to the specified design constraints.
2. Develop winding layouts and calculate the harmonic content of their MMF or of the EMF induced in the windings by a rotating field.
3. Suggest the choice of an appropriate permanent magnet material and its main dimensions when used in an electric machine.
4. Introduce different topologies of modern permanent magnet machines and actuators.
5. Calculate the copper and iron losses as well as temperature distribution within permanent magnet machines.
6. 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

1. Outline of course contents, rationale of the course, an overview of machine specification and limiting technologies, examples of computer-aided-design.
2. Development of the general output equation relating dimensions to output torque and electric and magnetic loadings.
3. Discussion of the limiting material properties and operational conditions on the output power.
4. Application of the output equation to specific motor topologies, design objectives and motor types.

5-6 Development of the general EMF equation for an ac winding taking account of coil span, winding distribution and skew. Calculation of harmonic winding factors.

7. Induced EMF due to a non-sinusoidal rotating field. Harmonic content of practical windings.
8. Resultant space and time harmonic fields for single and three-phase windings.

9-10. Three phase winding layouts, winding phase vectors, winding factors.

11. Permanent magnets, typical B/H characteristics, important properties, nomenclature and definition.
12. Equivalent circuit models, working points, graphical interpretation and critical design objectives.
13. Analytical models of magnet behaviour, calculation of open circuit flux density and demagnetisation conditions. Magnet recoil operation.
14. Calculation of magnet dimensions for specific operational conditions, minimum magnet volume conditions.

15-17. Calculation of torque in permanent magnet machines. Minimization of torque ripple (cogging and harmonics in back-EMF).

18-19. Introduction of actuator topologies.

20-23. Introduction of modern permanent magnet machine topologies. brushless DC/AC, fractional slot, switched/transvers flux as well as flux focusing permanent magnet machines, etc.

24. Review of equivalent circuit models for dc and ac machines.
25. Calculation of air-gap fields and winding reactance for concentrated and distributed windings. Relationship to main magnetic circuit dimensions.

26-27. Calculation of magnetizing reactance and major components of leakage reactance in machines.

28-29. Calculation of copper losses, stator and rotor iron losses, permanent magnet eddy current losses

30-31. Thermal phenomena: conduction, convection and radiation within electrical machines.

32-34. Lumped parameter, finite element thermal models. Temperature distribution within permanent magnet machines (steady state or transient for driving cycles).

35-36. Contingency and reading week.

UK-SPEC/IET Learning Outcomes

Outcome Code	Supporting Statement
SM1m / SM1fl	Electromagnetic and thermal principles for permanent magnet machines and actuators. These will be tested in the examination.
SM4m	Historic development of permanent magnet machines and actuators, different topologies and their main advantage/drawbacks are outlined.
SM2p	Mathematical modelling techniques for permanent magnet machines and actuators, special attention will be paid on the modelling of permanent magnet and windings and the thermal performance will be detailed. This will be tested in the examination.
SM2m / SM2fl	Modelling techniques applied to the analysis and design of permanent magnet machines and actuators, including analytical, lumped parameter and finite element modelling. The former two will be tested in the examination.
EA1p	The course is underpinned by engineering principles and their applications, and is fundamentally associated with some descriptors in Theme A: Electrical Engineering. Cover the application of electric and magnetic circuit laws for development of loss models for the permanent magnet machines and actuators and the application of lumped parameter models for the analysis of temperature variation, in order to determine the power and energy requirements. This will be tested in the examination.
EA1m / EA1fl	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.
EA2p	The course is underpinned by modelling technique, quantitative analysis and design against specific criteria such as electrical and magnetic loadings, performance and thermal limits, etc. Analytical equations describing sizing effect of electrical machines and actuators are derived. The optimization of permanent magnets and the calculation of winding inductances and reactance have been carried out. This will be 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.
EA3m	Formal design approach based on the mathematical modelling and analysis is presented for permanent magnet machines and actuators with consideration of materials' non-linearity and their thermal limits.
EA4p	The course materials underpin the modelling of different machine components such as permanent magnet and windings, analysis of machine performance and design against a given specification.
D1m / D1fl	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	The process of “investigate and define a problem” is covered throughout the course.
D2m / D2fl	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	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.
D3m / D3fl	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.
D5p	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.
D8m	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.
EP1p / EP1m	Concrete examples are given to illustrate how knowledge gained through the course is applied to a practical application. This will be tested in the examination.
EP2p / EP2m	Characteristics of permanent magnets are presented and analyzed. Their influence on the performance of designed machine is comprehensively introduced throughout the module. This will be tested in the examination.
EP9m	Current state-of-the-art of permanent magnet machines and actuators as well as their development of new topologies are outlined.
EP1fl	Characteristics of permanent magnets are presented and analyzed. Their influence on the performance of designed machine is comprehensively introduced throughout the module. This will be tested in the examination.
EP2fl	Current state-of-the-art of permanent magnet machines and actuators as well as their development of new topologies are outlined.
ET2m / 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.
ET4m / ET4fl	The students are taught to be aware of the recent trend of sustainable and renewable energy techniques.