The University Of Sheffield.

Electronic & Electrical Engineering.

EEE6203 MOTION CONTROL AND SERVO DRIVES

Credits: 15

Course Description including Aims

This unit builds upon the second year unit EEE223, "Electrical Energy Management and Conversion", to investigate in more detail the performance and operational characteristic of both modern a.c. and d.c. variable speed drives and actuation systems, as well as their applications in electric/hybrid vehicle traction and in flight control surface actuation. The unit also complements the module EEE307 "Power Electronics".

1. To introduce d.c. drives and permanent magnet brushless a.c. drives.
2. To examine in more detail the operational requirements of induction motors at variable speeds under scalar and vector controlled modes of operation.
3. To introduce power electronic inverters and develop control strategies and switching schemes for inverter fed drives.
4. To develop techniques for modelling the performance of drive systems and for their control system design.
5. To introduce electric and hybrid drive-trains and their components.
6. To model flight control surface actuation, and develop control strategy and control design techniques
7. To demonstrate the need for modelling and simulation in order to assess the benefits of a particular component and/or drive

Outline Syllabus

Introduction to servo drive systems: Drive system configuration, characteristics of mechanical loads, velocity profiles, matching motor and load, and criteria for selecting drive components. **D.C. machine drives**: Review of d.c. servo drive characteristics (4 quadrant operation), speed control, development of transfer function for both motor and drive subsystems, design techniques for current and speed control loops, power electronic converters for d.c. drives, supply considerations. **Permanent magnet brushless a.c. drives**: Rotating magnetic field of AC windings, operational characteristics of permanent magnet brushless motors, d-q axis transformation, and modelling and field-oriented control of permanent magnet a.c. machines. **Voltage source Inverters**: Inverter topology, review of operation, sinusoidal PWM modulation, switching harmonics, over modulation and six-step operation, space vector modulation and their implementation in a digital controller. **Induction motor drives**: Review of operation, development of phasor diagram and lumped circuit model, operational characteristics, speed control, scalar and vector control schemes. **Electric Traction**: Electric and hybrid drive-trains, modelling of drive-train components, vehicle kinematics, assessment of drive-train performance and efficiency, driving cycles and simulation. **Flight control surface actuation:** System overview and layout, transmission and kinematic equations, mechanical equations for motion, actuation system modelling, position servo control and controller design.

Time Allocation

36 lectures plus 12 hours of support material.

Recommended Previous Courses

Background knowledge equivalent to EEE223 “Electrical Energy Management and Conversion”, ACS342 “Feedback Systems Design” and EEE307 “Power Electronics”

Assessment

The course is assessed by

1. 2-hour examination, answer 3 questions from 4. 75%
2. Coursework, submit a written report and simulation models, 25%

Learning outcomes covered by assessment methods

Assessment methods	Learning outcomes
Exam.	SM1p, SM1m, SM2p, SM2m, EA1p, EA2p, EA3p, EA4p, EA3m, D2p, EP2p
Coursework	EA4p, EA4m, EP9m, EP1p, ET2p, ET4f1, ET5f1

Recommended Books

Williams B.W.	*Power Electronics - Devices, Drivers & Applications*	Macmillan
Miller T.J.E.	*Brushless Permanent-Magnet and Reluctance Motor Drives*	OUP
Leonhard, W.	*Control of Electrical Drives*	Springer
Mohan, N., Undeland, T.M. & Robbins, W.P.	*Power Electronics: Converters, Applications and Design*	John Wiley
Bose, B.K.	*Electronics and Variable Frequency Drives*	IEEE Press
I. Husain	*Electric and hybrid vehicles*	CRC Press, 2003
S.K. Sul	*Control of Electric Machines Drive Systems*	IEEE Press, 2011

Objectives

By the end of this module successful students will be able to

1. Describe alternative drive technologies for motion control systems.
2. Demonstrate detailed understanding of the operational characteristics of variable speed drive systems.
3. Use standard techniques for drive system modelling and control system design.
4. Display in-depth knowledge of power electronic converters/inverters used in modern drive systems, and their modulation schemes and control strategies.
5. Explain the principles of electric and hybrid drive-train architectures and their components as well as flight control surface actuations.
6. Model the components of electric and hybrid drive-trains, and flight control surface actuation systems.
7. Calculate the losses and efficiency of electric and hybrid drive-trains.

8. Assess the performance of vehicles equipped with electric and hybrid drive-trains and the performance of flight control surface actuations

Detailed Syllabus

1. Introduction and outline of course content. Review of characteristics of mechanical load (static and viscous friction and windage).

2,3. Velocity profiles (triangular, trapezoidal and parabolic), and matching motor and load.

4. Thermal considerations and criteria for selecting drive components.

5, 6. Revision of basic operation principles of permanent magnet and wound field d.c. motors. Operational characteristics.

7, 8. Speed control, modelling of d.c. motor and drive systems, and power electronic converters for d.c. drives. Considerations for power supply. Controller design for current and speed loops.

9,10,11. Introduction to brushless a.c. permanent magnet motors. Rotating magnetic field of AC machines. Phasor and two axis representation of field and induced voltage, operational characteristics and comparison with that of brushed d.c. motors.

12,13,14. D-q axis transformation, modelling and field-oriented control of permanent magnet a.c. machines. Current control structure and decoupling control, current and speed controller design, and real-time implementation.

15,16. Introduction to inverter topologies. Review of switching operation of a full bridge, 3 phase inverter. Sinusoidal PWM modulation.

17,18. Switching harmonics in PWM inverters. Over modulation and six-step operation. Space vector modulation and their implementation in a digital controller.

19,20. Revision of basic operating principles of induction motors. Development of phasor diagram and lumped circuit model. Operational characteristics.

21,22. V-f characteristics and speed control. Comparison of Scalar control and field-oriented control of induction machines. Discussion as to how field-oriented control is realised in practice.

23. Electric and hybrid drive-train architectures.

24-25. Modelling of the various components of electric and hybrid drive-trains, i.e. power electronic converters, brushless permanent magnet traction motors, and mechanical transmissions.

26. Introduce the differential equation governing the vehicle motion, including aerodynamic drag and rolling resistance.

27 Derive analytical equations for field weakening control of traction drives at high speeds.

28 Through a case study, demonstrate how the various modelling tools can be used to quantify the performance of the vehicle and the energy requirements and efficiency of the drive-train.

29. Discuss the need for simulation, in order to quantify the efficiency of drive-trains, and introduce the standard driving cycles used around the world.

30, 31 Flight control surface actuation system layout, mechanical transmission, kinematic and dynamic equations for the actuation system

32, 33 Actuation system modelling, position servo control strategy and controller design

34. Coursework tutorials for modelling and simulation of electric vehicle traction system and flight control surface actuation system

35-36. Contingency and reading week.

UK-SPEC/IET Learning Outcomes

Outcome Code	Supporting Statement
SM1p	Electromagnetic principles for rotating machinery used in modern electrical drives and methodology for feedback design of modern servo drive systems.

	Assessed by Exam
SM1m	Electromagnetic principles for rotating machinery and methodology for feedback design of modern servo drive systems applied in an engineering context. Assessed by Exam
SM4m	Historic development of electric drives and the current state-of the art are discussed through introduction of dc and ac drive technologies.
SM2p	Mathematical modelling techniques for electric drives Assessed by Exam
SM2m	Modelling techniques applied to the analysis and design of DC and Synchronous Permanent magnet motor drives, including pulse with modulation (PWM) and harmonic analysis Assessed by Exam The importance of simulation in assessing the performance of drive-trains is high-lighted and Matlab/Simulink is employed for the development of a model for an electric vehicle. Assessed by Exam
SM1fl	Electromagnetic principles for rotating machinery and methodology for feedback design of modern servo drive systems applied in an engineering context. Assessed by Exam
SM2fl	Historic development of electric drives and the current state-of the art are discussed through introduction of dc and ac drive technologies.
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 circuit laws for development of loss models for the electrical machine and associated power electronics and the application of Newton's law for the analysis of vehicle kinematics, in order to determine the power and energy requirements. Assessed by Exam
EA5m	The fundamental control principle for modern AC drive, i.e., the vector (or field oriented) control, three-phase inverters and their Space Vector PWM technique will allow students to investigate new and emerging technologies in electric drives
EA2p	The course is underpinned by modelling technique, quantitative analysis and design against specific criteria such as control bandwidth, performance and thermal limits, etc. Analytical equations describing the losses in the drive-train and other vehicle performance indicators are derived. Assessed by exam
EA3p	Problems are presented to the students for simulation study of the performance of a synchronous permanent magnet drive under the field oriented control in Matlab/Simulink environment. The development of Matlab/Simulink models of the vehicle and its drive-train are demonstrated through an example vehicle Assessed by exam
EA3m	Formal design approach based on the mathematical modelling and analysis is presented for servo drive systems with due consideration of non-linearity and thermal limits Assessed by exam
EA4p	The course materials for various drive technologies are treated in a system approach which entails the modelling of drive components, analysis of system performance and design against a given specification. Assessed by exam and coursework
EA4m	Integrated and system approaches to solving complex engineering problems are incorporated in the coursework tutorial and assignment Assessed by exam and

	coursework
EA2fl	The fundamental control principle for modern AC drive, i.e., the vector (or field oriented) control, three-phase inverters and their Space Vector PWM technique will allow students to investigate new and emerging technologies in electric drives
D2p / D2m	The process of "investigate and define a problem" is covered throughout the course Assessed by exam
EP2p / EP2m	Characteristics of motion control and servo drive systems are presented and analysed Assessed by exam
EP9m	Current state-of-the-art of motion control and servo drive systems and their trends for new technology development are outlined Assessed by coursework
EP1fl	Characteristics of motion control and servo drive systems are presented and analysed Assessed by exam. The economic and environmental drivers behind the development of fuel cells and electric and hybrid vehicles are discussed. For example, Oil price trends and proven reserve information is updated and presented Assessed by coursework
EP2fl	Current state-of-the-art of motion control and servo drive systems and their trends for new technology development are outlined Assessed by coursework
EP1p / EP1m	Examples are given to illustrate how knowledge gained through the course is applied to a practical system Assessed by coursework
ET2p / EP2m	The economic and environmental drivers behind the development of fuel cells and electric and hybrid vehicles are discussed. For example, Oil price trends and proven reserve information is updated and presented Assessed by coursework
ET4m	Awareness that engineering activities should promote sustainable development and ability to apply quantitative techniques is highlighted in electric vehicle traction system and flight control surface actuation for more electric aircraft technologies Assessed by coursework
ET4fl	Awareness that engineering activities should promote sustainable development and ability to apply quantitative techniques is highlighted in electric vehicle traction system and flight control surface actuation for "more electric aircraft" technologies Assessed by coursework
ET5fl	Awareness of relevant regulatory requirements governing engineering activities in the context of vehicle homologation is covered in part as regards the vehicle driving cycles Assessed by coursework