Unit T9: Control Engineering Design

Unit code: Y/503/7381
QCF level: 6
Credit value: 15

Aim

This aim of this unit is to enable learners to analyse control systems using frequency and time-response techniques for control system characterisation. Learners will also develop their understanding of, and skills in designing and synthesising, continuous and digital controllers.

Unit abstract

Control engineering is about improving system performance by designing a controller (ie, the interface between electro-mechanical components that results in an improvement in system characteristics) which are normally expressed in terms of equivalent second order under-damped time-response characteristics. An understanding of system classification and controller design, both analogue and digital, are key skills for electrical and mechanical engineers.

This unit covers the use of Laplace transforms as a means of determining system characteristics. Frequency response techniques (Bode, Nyquist and Nichols) are used to establish system characteristics in the frequency domain and to estimate equivalent second order under-damped time response characteristics. Learners will gain an understanding of lead and lag controller design and PID tuning techniques. Learners will gain skills to characterise digital control systems using Z-transforms also in terms of equivalent secondd order under-damped time response characteristics.

This unit also covers digital proportional integral differential controller synthesis and computer implementation by recursive difference equations.

Learning outcomes

On successful completion of this unit a learner will:

1 be able to use Laplace transforms in the analysis of control systems

2 be able to use frequency response data to characterise control systems

3 understand the processes of design and tuning of controllers

4 be able to analyse digital control systems

5 be able to synthesise digital control algorithms.

Unit content

1 **Be able to use Laplace transforms in the analysis of control systems**

Laplace transforms: the s-operator; definition of the Laplace transform of a function; use of a tables of Laplace transforms; inverse Laplace transforms

Transient analysis: poles and zeros; stability; the s-plane; 1st and 2nd order systems; time constant; 2nd order under-damped characteristics, eg

$\omega_d = \omega_n\sqrt{1-\zeta^2}, \omega_r = \omega_n\sqrt{1-2\zeta^2}, \cos\theta = \zeta$; time to 1st overshoot, $t = \frac{\pi}{\omega_d}$

% overshoot, $M_{pt} = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$

2 **Be able to use frequency response data to characterise control systems**

Frequency response plots: Bode; Nichols; Nyquist; stability; gain margin; phase margin; bandwidth

Equivalent under-damped second-order parameters: eg $M_{p\omega} = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$

$\omega_r = \omega_n\sqrt{1-2\zeta^2}, \omega_d = \omega_n\sqrt{1-\zeta^2}, \omega_d = \omega_n\sqrt{1-\zeta^2}$, time to 1st overshoot,

$t = \frac{\pi}{\omega_d}$, % overshoot, $M_{pt} = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$

3 **Understand the processes of design and tuning of controllers**

Similarity between phase-lead, phase-lag, and proportional+differential (PD) and proportional+integral (PI) controllers: analytical analysis: s-plane analysis; frequency response analysis

Design of phase-lead and phase-lag compensators in the frequency domain: closed loop specification; analytical analysis; graphical analysis; computer-based analysis

The three-term proportional+integral+differential (PID) controller: tuning techniques, eg manual, Zeigler-Nichols, Tyreus-Luyben, tuning software

4 **Be able to analyse digital control systems**

The sampling process: analogue to digital conversion; word length; quantisation error; Shannon/Nyquist sampling theory

The Z transform: open and closed loop pulse transfer functions; the zero-order-hold; aliasing; anti-aliasing; inverse Z transform; time response; difference equations

The z-plane: stability; unit circle; equivalent under-damped 2nd order time response parameters eg, Modulus of z: ($|z| = e^{-\zeta\omega_n T}$), Angle of z: ($\angle z = \omega_d T$)

5 **Be able to synthesise digital control algorithms**

Digital controller synthesis: forward difference integration; backward difference integration; digital PI, PD and PID control algorithms; recursive equations; computer implementation

Learning outcomes and assessment criteria

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
	1.1 Use Laplace transform tables to define transfer function representations of control systems 1.2 Use inverse Laplace transforms to determine transient analysis and time responses of first and second order systems
LO2 Be able to use frequency response data to characterise control systems	2.1 Construct Bode, Nyquist frequency response plots and Nichols charts using measured or calculated data 2.2 Use frequency response data to determine control system stability margins, resonant frequency (ω_r) and bandwidth 2.3 Use frequency response plots to estimate equivalent under damped second order system time response characteristics
LO3 Understand the processes of design and tuning of controllers	3.1 Describe the relationship between PD and PI controllers, and their approximate phase-lead and phase-lag counterparts 3.2 Describe in detail the design process for phase-lead and phase-lag controllers to meet closed-loop specification 3.3 Critically appraise proportional+integral+ differential controller tuning technniques
LO4 Be able to analyse digital control systems	4.1 Describe the sampling process for digital control systems 4.2 Determine pulse transfer functions for open and closed-loop digital control systems 4.3 Determine time response at sample instants using inverse Z transforms, synthetic division and difference equations 4.4 Use the z-plane to analyse digital control system stability 4.5 Estimate equivalent 2nd order parameters under damped time response characteristics
LO5 Be able to synthesise digital control algorithms	5.1 Develop z-transform representations for digital proportional+integral (PI), proporational+differential (PD) and proportional+integral+differential (PID) controllers 5.2 Synthesise digital control algorithms.

Guidance

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

The learning outcomes associated with this unit are closely linked with:

Level 4	Level 5	Level 6
Unit 1: Analytical Methods for Engineers	*Unit 43: Plant and Process Principles*	*Unit T7: Modelling and Simulation for Engineers*
	Unit 59: Advanced Mathematics for Engineering	

The content of this unit has been designed and mapped against the Engineering Council's current Learning Outcomes for IEng Accreditation. The completion of the learning outcomes for this unit will contribute knowledge, understanding and skills towards the evidence requirements for IEng Registration.

See *Annexe B* for summary of mapping information for IEng Accreditation.

Assessment

Assessment should be based on laboratory work, using MATLAB/Simulink for controller design and evaluation.

Resources

Use of MATLAB/Simulink will significantly enhance the delivery of this unit.

Books

Bolton W – *Control Engineering* (Prentice Hall, 1998) ISBN 978-0582327733

Dorf R C and Bishop R H – *Modern Control Engineering* (Pearson International, 2008) ISBN 978-0132270283

Kuo B C and Golnaraghi F – *Automatic Control Systems* (John Wiley & Sons, 2002) ISBN 978-0471134763

Nise N – *Control Systems Engineering*, 5th edition (John Wiley & Sons, 2008) ISBN 978-0470169971

Ogata K – *Modern Control Engineering*, 5th edition (Pearson Education, 2008) ISBN 978-0137133376