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Teaching of Process Control

Dear Colleague

I would like to draw to your attention an excellent piece of work in relation to the teaching of process control, developed by the Process Management and Control Subject Group of IChemE together with a number of industry and academic stakeholders.

This work was initiated because of an expressed general dissatisfaction, within this specialist community, regarding the skills and competencies of new graduates in this area - coupled with a concerned awareness of the lack of practical relevance of what is generally been taught at the undergraduate level. It is perceived, for example, that undergraduate programmes may focus on the mathematical aspects rather than upon the practical implementation of more modern computer-based process control.

The PMCSG has therefore gone through a process of consultation, involving both senior industrialists and academics, the outcome of which is a recommendation regarding syllabus content (attached). Syllabus content aims to strike a sensible balance between conventional and modern theory & practice; technique & technology; information & understanding; breadth & depth.

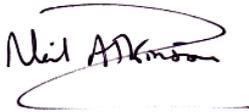
For accreditation purposes IChemE deliberately does not seek to over-specify curriculum content. Indeed, our principle is one of allowing flexibility to departments to provide innovative curricula design that meet overall Learning Outcomes in chemical engineering as defined in our formal Guidance Accreditation. We therefore do not expect all Departments to rigorously adopt the recommended syllabus of the PMCSG given the often competing constraints of curriculum demands. We do, however, commend this work to you as an example of good practice and would encourage your colleagues to consider the elements carefully.

Some of the aspects of the curriculum may appear daunting. In recognition of this the PMCSG has kindly offered, in good faith, and where practicable, to assist in the provision of appropriate support and learning resources. The PMCSG will be actively considering responses to this work and would welcome any suggestions you would have. Please kindly send any such input to PMCSG Chairman Andrew Ogden-Swift (Andrew.ogden-swift@honeywell.com) with cc to me (natkinson@icheme.org).

IChemE is conscious of the need to successfully prepare the majority of chemical engineering graduates for a successful career in industry (their major destination). This is one example of a useful constructive feedback and IChemE will continue to look for ways to help enrich undergraduate programmes. The teaching of design is another such key topic area on which we are hoping to share best practice.

With best regards,

Yours Sincerely

A handwritten signature in black ink that reads "Neil Atkinson". The signature is stylized with a large, sweeping flourish that extends to the right and then loops back under the name.

Neil Atkinson
Director - Qualifications and International Development

cc Professor C Webb Chair - Accreditation Committee
A Ogden-Swift
A Furlong

Attached : Skill Requirements in Process Automation for Graduate Chemical Engineers

Skill Requirements in Process Automation for Graduate Chemical Engineers

In the context of this document, process automation is deemed to embrace not just the immediate objectives of instrumentation, process control and operations but also the wider issues of optimisation and enterprise management.

There is a presumption that those responsible for the design and delivery of degree courses in chemical engineering recognise and accept that process automation is fundamental to and pervades all aspects of the operability, quality, reliability, safety and viability of processes and plant.

Overview Of Document

Whilst it is recognised that a grounding in chemical engineering is a good basis for careers in a variety of sectors, this document concerns skills levels for graduate chemical engineers whose intent is to become employed in the chemical and process industries.

The skills levels are those that are considered to be required of new graduates by senior industrialists from a number of leading companies, including:

ABB	Fluor
BOC Gases	Foster-Wheeler
BP	Honeywell Process Solutions
Eli Lilly	SABIC UK Petrochemicals
Emerson Process Management	Siemens Automation and Drives

Noting the distinction between education and training, the skills requirements have been cast in the form of aims and objectives consistent with the ethos of higher education. This document has been reviewed by academics from Imperial College and the Universities of Manchester, Newcastle and Sheffield.

Introduction to Skill Requirements

There are two categories of chemical engineering graduate that this document provides for:

- i those that will pursue a **general** career in chemical engineering such as in process development, plant design and project management, operations and plant management for whom a good working knowledge of process control is required.
- ii those working in more **specialist** areas such as process analysis, systems design and specification and advanced process operations such as real time optimisation for whom a more in-depth understanding of process automation is required.

It is assumed that students will be familiar with the concepts of ordinary differential equations, Laplace transforms, matrices and statistics and have had practice in the use and manipulation of such for solving problems from studies done in separate modules in mathematics.

General Careers in Chemical Engineering

It is **expected** that the following aims and objectives will be realised through some 20 credits worth of tuition (one u/g academic year = 120 credits). This should be **core** (compulsory) syllabus content. Ideally it would be delivered in year 2 of an MEng/BEng degree course but could be split between years 2 and 3.

Aims

The broad aims are that the student should:

- understand the essential functionality of feedback control loops of a PID nature, the common elements of which they are comprised, and their operation.
- be familiar with a variety of conventional control strategies and the circumstances in which their potential benefits may be realised.
- be aware of a range of schemes for the control of a variety of items of plant and to be able to assess from underlying process considerations the suitability of such schemes according to context.
- be able to develop models, especially qualitative models, of cause and effect (input-output) relationships and to be able to interpret P&I diagrams in terms of CVs, MVs, DVs, etc.
- have an awareness of the functionality of typical proprietary DCS, SCADA and PLC systems from the perspective of the operator.

Objectives

The specific objectives, or learning outcomes, are that the student should be able to do **most** of the following:

- 1 interpret the function of control loops articulated by means of typical symbols, bubbles and tag numbers on P&I diagrams.
- 2 appreciate the different nature of and different types of signal involved in a process control system such as process vs control, electrical vs pneumatic, analogue vs discrete.
- 3 articulate the criteria used for specifying instrumentation, whether used for monitoring or control purposes, in terms of reliability, repeatability, reproducibility, drift, cost, delay, etc.
- 4 explain the alternative uses of the dp cell, with impulse lines and isolating valves, in terms of installation, commissioning and operation.
- 5 describe the principal features and principles of operation of instrumentation commonly used for the measurement of flow, level, pressure and temperature.
- 6 describe the principal features and principle of operation of common valve types, especially the pneumatically actuated globe valve.
- 7 distinguish between a valve's inherent and installed characteristic, appreciate the principles of valve sizing and be able to interpret a valve's size in terms of its Kv or Cv value and the pressure drop available.
- 8 explain the concept of hazardous area, the basis of zoning, intrinsic safety and certification of such, describe the principal types of protection such as the use flameproof enclosures, and the use and specification of barriers.

- 9 explain, from a process operation point of view, the purpose of a single loop feedback control system and the typical effects of failure of a loop to function effectively.
- 10 identify the controlled, manipulated and disturbance variables for the control schemes of typical items of plant and/or processes.
- 11 articulate the functionality of a conventional feedback control loop in block diagram form, qualitatively, distinguishing between inputs and outputs from a process and from a control perspective.
- 12 translate loops from a P&I diagram into block diagram form, qualitatively.
- 13 describe the difference between different modes of operation such as automatic vs manual, open vs closed loop, steady state vs dynamic, regulo vs servo, continuous vs batch, etc.
- 14 explain the operation of a PID controller and the effect on the closed loop's response of varying the controller's proportional gain, reset time and rate time, and be able to troubleshoot the symptoms of a faulty loop.
- 15 appreciate the nature of closed loop instability, distinguish between exponential and oscillatory response, and characterise the response to simple inputs such as step and ramp in terms of offset, damping and settling time.
- 16 describe the principles underlying classical methods of controller tuning, such as continuous cycling and reaction curve, be familiar with the Ziegler & Nichols and related formulae, appreciate the pros and cons of such methods, and be aware of the functionality of modern tuning and loop health monitoring tools.
- 17 explain the structure, in block diagram form, and functionality of the various control strategies based upon the conventional feedback control: that is, cascade control, ratio control and feedforward control.
- 18 appreciate the concepts and consequences of a process being over/under determined and properly determined.
- 19 establish from heat and/or mass balance considerations the strategic variables of a process unit, determine its number of degrees of freedom, and reconcile those degrees of freedom with the system's wild, controlled, manipulated and inventory variables.
- 20 develop simple schemes for the control of a selection of items of plant such as heat exchangers, evaporators, reactors and separation columns.
- 21 describe simple process dynamics in terms of gain (steady state), time lag and lead (time constant), delay (deadtime) and integrator, and distinguish between self-regulating and integrating processes.
- 22 explain the nature of the step response of a second order system in terms of its damping factor and, for an underdamped system, characterise its response in terms of rise time, settling time, etc,

- 23 recognise dynamic process models represented in transfer function form (Laplace transforms).
- 24 develop a transfer function model of a simple dynamic process from first principles, involving heat and/or mass balances, and determine its response to simple inputs such as step and ramp.
- 25 describe the principal features of the operator's interface of typical proprietary DCS, SCADA and PLC systems, appreciate the importance of human factors in the design of such and current best practices.
- 26 distinguish between alarms, trips and interlocks, describe the functionality of an integrated alarm environment as supported by a typical proprietary control system, and appreciate best practice regarding alarm management.

Specialisation in Process Automation

It is anticipated that the following aims and objectives will be realised through additional tuition. This should be of an optional nature, building upon the content described under 'general careers in chemical engineering' as described above. It is recommended that this be a minimum of 20 credits worth of tuition. Ideally it would be delivered in year 3 of a BEng degree course, but could be split between years 3 and 4 of an MEng degree. It is also suitable for inclusion in an MSc course.

Engineering undergraduates and graduates who are interested in more in depth studies of process automation, with possible interest in pursuing careers in the field, should demonstrate **a significant proportion of** the capabilities listed below.

Aims

The broad aims are that the student should:

- understand the essential functionality of the technology of typical proprietary DCS, SCADA and PLC systems.
- appreciate the contribution of control technology to safety through intrinsic safety, alarm handling, design of protection systems, etc.
- understand the differences between continuous and batch process control and appreciate the special system requirements for batch control.
- be aware of the life cycle of a control system and familiar with good practice in relation to the management of projects and systems.
- be able to develop transfer function models of items of plant from first principles and to simulate such using Simulink.
- be familiar with the essential principles of the techniques of linear control system design and analysis and appreciate how and when to use them.
- have a qualitative awareness of the underlying principles and the pros and cons of a selection of advanced control and automation techniques.

Objectives

The specific objectives, or learning outcomes, are that the student should be able to do a **significant proportion** of the following:

- 27 describe the architecture of typical proprietary control systems and their organisation in terms of hardware, communications and system software.
- 28 explain the route taken by signals through typical I/O channels, both analogue and discrete, in terms of field instrumentation, barriers, I/O cards, sampling, configurable software, etc.
- 29 explain the underlying principles of key communications protocols and standards such as Ethernet, HART, Profibus, etc, and appreciate the benefits, potential uses (such as asset management) and limitations of fieldbus technologies and wireless transmission.
- 30 appreciate the concept of open systems, the significance of OPC, the risks from unauthorised access, etc, the need for information security management and describe the principal means of protection by firewalls, etc.
- 31 describe the structure of a relational database in terms of attributes, keys, relations and schema, and construct SQL statements in terms of keywords and arguments for abstracting information from data.
- 32 explain the basic concepts of management information systems (MIS), appreciate the distinction between data and information, real-time or otherwise, and understand how MIS technology contributes to profitability but also its cost of application and maintenance.
- 33 appreciate the nature of materials and resource planning (MRP), manufacturing execution systems (MES) and enterprise resource planning (ERP), and how these technologies relate to supply chain issues and standards such as ISA S95.
- 34 find trends and correlations in data (both univariate and multivariate) using the techniques of control charts, correlation functions (both auto and cross), data visualisation and linear regression analysis (both simple and multiple), and appreciate the importance of pre-screening of data, appropriate selection of variables and validation of results.
- 35 explain the nature of a principal component and the concept of PCA in terms of variance and orthogonality, formulate data into covariance and/or correlation matrices, be aware of the pros and cons of such, abstract weightings from eigenvectors, appreciate the basis for reduction in dimensionality, and interpret scores and loadings plots.
- 36 describe the concept of layers of safety and articulate the meaning of terms such as demand rate, hazard, risk and safety integrity level (SIL) in the context of a safety instrumented system (SIS) type of protection system design.
- 37 define the terminology of reliability, such as failure rate, MTBF, availability, etc, understand the concepts of proof testing, common mode failure, voting, etc, and evaluate the PFD of protection systems comprised of multiple channels.

- 38 specify the SIL requirement of a protection system by quantifying demand rate from fault tree analysis through to determining PFD and verify such qualitatively by means of risk graph and/or hazardous event severity matrix.
- 39 articulate the requirements for sequence control in the form of flow charts subject to the constraints of process logic, plant status, timing requirements and abnormal condition handling.
- 40 translate such into sequential function charts with transitions and steps, the latter decomposed into actions, understand the logic of sequence progression and appreciate good practice with regard to sequence structure and parallelism.
- 41 distinguish between continuous, batch and semi-batch process control applications, be familiar with the terminology of IEC61512 (also referred to as S88) and explain how the recipe, physical and procedural models of such relate to each other.
- 42 estimate the costs of a control system and be able to identify potential benefits, and quantify such, for the automation of a process and/or plant.
- 43 identify the key stages of the life cycle of a project for developing a process control system, from its initial justification right through to operation and maintenance, and be aware of good practice regarding the roles and responsibilities of the different parties involved.
- 44 recognise the importance of user requirements, detailed functional, test and acceptance specifications for developing a control system and relate these to the waterfall model of the project life cycle.
- 45 develop transfer function models for a variety of processes, items of plant, instrumentation, etc, from first principles, using linear approximations and deviation variables.
- 46 use block diagram algebra to determine overall transfer functions, both open and closed loop, and hence establish responses of such to simple inputs.
- 47 establish the characteristic equation of a closed loop system and relate the step response and stability of the system to the position of its open/closed loop poles and zeros in the s plane.
- 48 describe the frequency response of a variety of transfer functions in terms of attenuation and phase shift, sketch Bode diagrams and polar plots of such, appreciate the nature of gain and phase margin, and relate critical frequency to closed loop stability.
- 49 sketch the root locus of simple closed loop systems and use the locus for specifying controller parameters (gain, reset time, etc) based upon the concepts of dominant poles and pole placement.
- 50 manipulate differential equations for both open and closed loop systems into state space or matrix form and solve such for both SISO and MIMO systems.

- 51 explain the principles of design of a state feedback controller law, specify a controller and its set point, design a full order observer and integrate with the controller, and appreciate the limitations on the use of state feedback.
- 52 recognise that many systems are inherently multivariable but that effective control can be realised by means of multiple SISO loops, and appreciate the use and limitations of RGA for assigning MVs to CVs.
- 53 understand the nature of interactions in MIMO systems, recognise the importance of diagonalisation as a design technique, and appreciate the functionality, use and limitations of cross compensators and decouplers.
- 54 explain the concept of a model predictive controller (MPC) in terms of receding horizon and the prediction cycle, recognise that MPC can be used in both SISO and MIMO context, describe the types of model used and approaches to model building, understand the significance of constraint handling, and appreciate the potential benefits of MPC.
- 55 appreciate that there are many approaches to adaptive control, ranging from gain scheduling and auto tuners through to self tuning controllers and model reference adaptive control, recognise situations where adaptive control could potentially be of benefit but also the constraints associated with the complexity involved.
- 56 describe the structure of a fuzzy logic controller, the process of fuzzification, the standardised rule base, use of decision logic and defuzzification, and explain the circumstances in which fuzzy control can be beneficial.
- 57 explain the structure of a multilayer perceptron type of neural net, notation used for weightings, pre-processing of data, training and back propagation, network size and generalisation, use and limitations of NNs for identification, modelling (SS and dynamic) and inferential estimation.
- 58 distinguish between knowledge based systems and expert systems, explain the principles of inferencing (esp chaining and inheritance), frame based systems and the expert system control cycle, describe the process of knowledge elicitation and the pros and cons of the use of expert systems for decision support.
- 59 distinguish between planning, scheduling and real time optimisation, and identify situations in which their application could be beneficial.
- 60 formulate an LP problem with two decision variables subject to inequality constraints, solve such using graphical means and appreciate the concept of corner feasible solutions.
- 61 explain the principle of MILP by extrapolation from LP using the techniques of implicit enumeration and branch and bound.
- 62 describe the differences between steady state and dynamic optimising categories of real-time optimiser in terms of the types, size and scope of model used, constraints, update mechanism, recursion cycle time, solution, relationship with MPC and application.

9th October 2008