National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute

Technology of Inorganic Substances, Water Treatment and General Chemical Technology Department

Advanced Process Control

Syllabus

Course Details

Level of higher education	***second (master's)***
Branch of knowledge	*16 Chemical Engineering and Bioengineering*
Specialty	*161 Chemical technology and engineering*
Educational program	*Chemical Technologies of Inorganic, Electrode Materials and Water Treatment*
Discipline status	*Optional (elective) subject*
Form of study	*Blended*
Year of study, semester	*1st year, spring semester*
The scope of discipline	*4 credits*
Semester control / control measures	*pass-fail test*
Timetable	*Lecture 1 hours a week (1 class for two weeks), computer workshop 2 hours (1 class each week) according to the schedule on rozklad.kpi.ua*
language of study	*English*
Information on the course leading teacher/ teachers	Lecturer: *PhD, Associate Professor Olga Sanginova, sanginova.olga@lll.kpi.ua, Telegram: @OlhaSan* Computer workshop: *PhD, Associate Professor Olga Sanginova, sanginova.olga@lll.kpi.ua*
Access to the course	Google Classroom (Google G Suite for Education, e-learning Sikorsky-distance platforme); access at the teacher invitation

Curriculum

1. **Course description and target, subject of study and learning outcomes**

Modern technological processes of the chemical industry have a relatively high level of automation and a chemical technology engineer must not only maintain and improve technological processes, but also know approaches of their control. An information on the technological process, which is provided by control systems, will improve the quality of products, and conduct the process in a trouble-free mode.

***The subject of the course**: process control systems (PCS), programmable logic controllers (PLC), a distributed control systems (DCS), and a supervisory control.*

The course aim is to form students' abilities:

- *understand the processes and phenomena in the chemical industry, analyze production and technological systems as objects of automation, determine the methods and strategies of their automation;*
- *use the system research apparatus to assess the functioning of technological systems in the industry;*
- *apply modern methods of control theory to industrial facilities;*
- *to use professionally profiled knowledge and practical skills in the field of the theory of automatic control for automation of technological processes and systems;*

- *ability to implement, operate and upgrade individual technical means, automation systems and computer-integrated technological complexes;*
- *use computer technology for computational analysis and structural synthesis of technological systems in the industry.*

After mastering the discipline, students must demonstrate the following learning outcomes:

knowledge:

- *current and advanced scientific research and development in the computer-integrated manufacturing system technologies, the main directions of PCS development, application of computer-integrated and information technologies in manufacturing;*
- *control systems classification;*
- *PCS design concept;*
- *PCS hierarchy;*
- *PLC, PCS and DCS technical and maintenance support;*
- *PCS unit properties;*
- *PCS applied equation solving methods;*
- *time characteristics of the PCS devices;*
- *stability assessment criteria the of the PCS;*
- *process control quality analysis.*

skills:

- *to analyze the technological process as a control object;*
- *to develop the control subsystem algorithmic structure both for individual technological processes, and for chemical manufacturing;*
- *to analyze the dynamic system mathematical model;*
- *to study the behavior of dynamic system individual elements and the system as a whole;*
- *the linear system stability assessment and an action increasing system stability;*
- *to determine frequency characteristics;*
- *analyze the system elements impact on process quality indicators;*
- *to develop software for microprocessor control systems, PLC and human-machine interface tools.*

experience:

- *control theory methods application for decision-making on a system technical units' optimum settings choice;*
- *application of the PCS technologies to chemical-technological processes.*

2. Prerequisites and post-requisites of the course (place in the structural and logical scheme of education according to the relevant educational program)

The list of disciplines, knowledge and skills that the student needs to successfully master the discipline:

Calculus, Numerical Methods, General Chemical Technology, Chemical Technological Processes Control.

Use of learning outcomes: to perform a master's thesis, in further professional activities.

3. The course contents

Topic 1. Fundamentals of building process control systems. Basic concepts and general information.

Chemical plant automation features. Terminological base. Process control systems, their features and distinctions. Parameters of technological processes. Control systems classification. Process control systems, their targets, and functions. PCS architecture. Levels of organization of modern PCS.

Topic 2. Technological processes as control objects.

System analysis of technological processes. Objects with concentrated and distributed parameters. Types of disturbances. Single-capacity and multi-capacity objects. Accumulation capacity of control objects. Self-aligning controls (stable, unstable, and neutral control objects). Inertia and delay of control objects.

Topic 3. Mathematical models of control systems.

Formalized mathematical methods of control system properties describing.

Statics of control systems. Static characteristics. The use of static characteristics in the control practice. Linear and nonlinear static characteristics. Static characteristics linearization methods. Static characteristics of link connections. Methods for determining static characteristics.

Dynamics of control systems. Dynamic characteristics. Differential equations for control system dynamics describing. Calculation of free and forced processes in the system. The superposition principle. Typical input effects. Transients. Determination of transient characteristics using the classical method and using the method of operational calculus.

Transfer functions. Definition of the transfer function of a group of elements. Transfer function of feedback control system. Transfer functions of Open-loop and closed-loop control systems.

Frequency response method. Bode magnitude and bode phase plot. Frequency response forms. Frequency characteristics of open-loop and closed-loop control system. Free and disturbed movement of control systems. Control systems stability. Lyapunov, Gurvits, Mikhailov and Nyquist stability criteria.

Control quality assessment using transient process and frequency characteristics. Mathematical models of logic control. Discrete control systems. Digital regulators.

Topic 4. Process control systems.

Integrated industrial process control systems and distributed process control systems. Principles of PCS construction. The system principle of construction and functional structure of PCS. The structure of modern PCS. Functional block diagram of a PCS. The architectures of modern PCS. Interrelation of control system design and production management. Typical structure of PCS. Hierarchical levels of the control object. The software and hardware structure that provides the PCS functions.

PCS operation modes. Typical management tasks in PCS. The PCS supervisory mode. Tasks and structure of PCS. Input / Output-Field level. Control level. HMI level.

PCS main functions. Composition and goals of PCS typical control functions. Composition and tasks of PCS auxiliary functions. PCS technical support and structure of a technical means. PCS software, its composition, and tasks. PCS information support. PCS organizational support.

Characteristics of typical SCADA. Network tools, protocols and workstations. Ethernet network architecture. SCADA software and hardware. Computing networks and nodes of DCS levels. Enterprise resource planning systems (ERP-systems). Production management systems (MES-systems).

4. Teaching materials and resources

The teaching materials listed below are available in the university library and in the library of the Department of Inorganic Substances Technology, Water Treatment and General Chemical Technology. Basic literature is required for study, other materials are optional. Sections and topics that the student should get acquainted with on their own, the teacher notes in lectures and practical classes.

Basic:

1. *Автоматическое управление в химической промышленности: Учебник для вузов. / Под ред. Е.Г. Дудникова. – М.: Химия, 1987. – 368с.*
2. *Медведєв Р.Б. Керування хіміко-технологічними процесами. /Навчальний посібник/. – К.: НТУУ «КПІ», 2012. – 192с.*
3. *Втюрин В.А. Автоматизированные системы управления технологическими процессами. Основы АСКТП. Учебное пособие. / – СПб.: 2006. – 152с.*

Optional

4. *Ельперін І.В. Промислові контролери: Навчальний посібник / І.В. Ельперін; Національний університет харчових технологій. – К.: НУХТ, 2003. – 320 с.*
5. *Гончаренко Б.М. Цифрові системи керування: Навчальний посібник / Б.М. Гончаренко, О.П. Лобок, А.П. Ладанюк. – Вінниця: Нова книга, 2007. – 160 с.*
6. *Трегуб В.Г. Основи комп'ютерно-інтегрованого управління: Навчальний посібник / В. Г. Трегуб; Національний університет харчових технологій. – К.: НУХТ, 2006 – 139 с.*
7. *Промислові засоби автоматизації / А.К. Бабченко та інш. – Харків.: НТУ «ХПІ», 2001. – 470 с.*
8. *Теорія автоматичного керування: методичні вказівки і завдання до виконання домашньої контрольної роботи та самостійної роботи для студентів напряму підготовки 6.050202 «Автоматизація та комп'ютерно-інтегровані технології» / Автори: Бондаренко С.Г., Сангінова О.В. – К.: НТУУ "КПІ", 2013. – 108 с.*
9. *Полоцкий Л.М. , Лапшенков Г.И. Автоматизация химических производств. Теория, расчет и проектирование систем автоматизации. - М. : Химия, 1982. - 296 с.*
10. *Ротач В. Я. Расчет настройки промышленных систем регулирования. М. : Энергия, 1973 - 440 с.*

Information resources

11. *E-course Google G Suite for Education. Access mode: Google Classroom (Google G Suite for Education, домен LLL.kpi.ua, e-learning Sikorsky-distance platforme); access by invitation of teacher.*

Educational content

5. The course/educational component mastering methods

Lectures

Lectures are held in parallel with the students' work on a computer workshop and their consideration of issues submitted for independent work. When giving lectures in blended learning, video conferencing tools (Google Meet, Zoom, etc.) and teaching material in the form of presentations are used, which are posted on the Sikorsky-distance platform [11]. After each lecture it is recommended to get acquainted with the materials recommended for independent study, and before the next lecture - to repeat the material of the previous one.

№	Lecture brief description
1	*Topic 1 - Fundamentals of building process control systems. Basic concepts and general information: The subject of study and the course tasks. Chemical plant automation features. Terminological base. Process control systems, their features and distinctions. Parameters of technological processes. Control systems classification. Process control systems, their targets, and functions. PCS architecture. Levels of organization of modern PCS.*
2	*Topic 2 - Technological processes as control objects: System analysis of technological processes. Objects with concentrated and distributed parameters. Types of disturbances. Single-capacity and multi-capacity objects. Accumulation capacity of control objects. Self-aligning controls (stable, unstable, and neutral control objects). Inertia and delay of control objects.*
3	*Topic 3 - Mathematical models of control systems: Formalized mathematical methods of control system properties describing.* *Statics of control systems. Static characteristics. The use of static characteristics in the control practice. Linear and nonlinear static characteristics. Static characteristics linearization methods. Static characteristics of link connections. Methods for determining static characteristics.*
4	*Continuation of the Topic 3: Dynamics of control systems. Dynamic characteristics. Differential equations for control system dynamics describing. Calculation of free and forced processes in the system. The superposition principle. Typical input effects. Transients. Determination of transient characteristics using the classical method and using the method of operational calculus.*
5	*Continuation of the Topic 3: Transfer functions. Definition of the transfer function of a group of elements. Transfer function of feedback control system. Transfer functions of Open-loop and closed-loop control systems.*
6	*Continuation of the Topic 3: Frequency response method. Bode magnitude and bode phase plot. Frequency response forms. Frequency characteristics of open-loop and closed-loop control system. Free and disturbed movement of control systems. Control systems stability. Lyapunov, Gurvits, Mikhailov and Nyquist stability criteria.*
7	*Continuation of the Topic 3: Control quality assessment using transient process and frequency characteristics. Mathematical models of logic control. Discrete control systems. Digital regulators. P-, PI-, PID-controller parameter determination corresponding to the set stability margin, using frequency characteristics.*
8	*Topic 4 - Process control systems: Integrated industrial process control systems and distributed process control systems. Principles of PCS construction. The system principle of construction and functional structure of PCS. The structure of modern PCS. Functional block diagram of a PCS. The architectures of modern PCS. Interrelation of control system design and production management. Typical structure of PCS. Hierarchical levels of the control object. The software and hardware structure that provides the PCS functions.* *PCS operation modes. Typical management tasks in PCS. The PCS supervisory mode. Tasks and structure of PCS. Input / Output-Field level. Control level. HMI level.*
9	*Continuation of the Topic 4: PCS main functions. Composition and goals of PCS typical control functions. Composition and tasks of PCS auxiliary functions. PCS technical support and structure of a technical means. PCS software, its composition, and tasks. PCS information support. PCS organizational support.* *Characteristics of typical SCADA. Network tools, protocols and workstations. Ethernet network architecture. SCADA software and hardware. Computing networks and nodes of DCS levels. Enterprise resource planning systems (ERP-systems). Production management systems (MES-systems).*

Computer workshops

The computer workshop aims to consolidate the theoretical knowledge gained in lectures and knowledge obtained in the process of literary studying of the discipline " Advanced Process Control". The material of the computer workshop is aimed at gaining experience in solving practical problems of chemical technology, studying the behavior of control systems on equipment that is typical of the chemical industry in order to practically confirm certain theoretical positions, acquiring skills and processing results.

Week of study	**Topic**	**Computer workshop task**
1	Control object statics models	Investigate the process of a complex control object statics model obtaining. Acquire the skills of static characteristics construction and analysis.
2		Task 1 defence is based on individual tasks using interactive tools such as Google Forms, menti.com, Kahoot, etc.
	Control object dynamic models	Investigate the process of the control system time characteristics obtaining with a known mathematical description of studied control system dynamics.
3		Gain the ability to solve differential equations using classical and operational methods.
4	Task 2 defence is based on individual tasks using interactive tools such as Google Forms, menti.com, Kahoot, etc.	
5	Stability Criteria	Investigate the process of control system stability evaluation using algebraic stability criteria. Gain the ability to determine the control system stability using the root criterion.
6		Gain the ability to determine the control system stability using Hurwitz criterion.
7	Task 3 defence is based on individual tasks using interactive tools such as Google Forms, menti.com, Kahoot, etc.	
8	Process parameter control circuit synthesis	Gain the ability to configure standard interfaces for control objects. Acquire the ability to configure the Arduino / Genuino 101 microprocessor board and the appropriate software to working with measuring tools. Investigate the factors that affect the measurement process and ways to adjust the signals.
8	Task 4 defence is based on individual tasks using interactive tools such as Google Forms, menti.com, Kahoot, etc.	
9	Heating control of technological mixture in the furnace	Investigate the process of heating control of the technological mixture in the furnace using a controller. Gain experience in using the controller in the chemical processes control.
10	Task 5 defence is based on individual tasks using interactive tools such as Google Forms, menti.com, Kahoot, etc.	
11	Alarm and process parameters registration setting of a thermal object in real time	Investigate the process of technological parameter alarm circuits creating and plot creating in the thermal object control using a controller. Gain experience working with alarms and plots in the chemical process control.

Week of study	Topic	Computer workshop task
12	Task 6 defence is based on individual tasks using interactive tools such as Google Forms, menti.com, Kahoot, etc.	
13	SCADA-systems	Network tools, protocols and workstations. Ethernet network architecture. Use of SCADA software and hardware.
14		Computing networks and nodes at the different DCS levels. Examples of typical SCADA-programs.
15	Module test	
16	Individual task defence is based on individual tasks using interactive tools such as Google Forms, menti.com, Kahoot, etc.	
17	Concluding classes	Students are informed of the total points they scored during the semester. Students who have not been admitted to the semester control must eliminate the reasons that led to this.
18	Final classes	Final test is conducted with those students who could not get a score more than 60%, but were admitted to the final test, as well as with those who want to increase their score.

6. Independent work of student

The student's independent work (SIW) during the semester includes lecture material studying, preliminary programs preparation for calculations in class, computer workshop reports preparation, individual task performance, computer workshops, module test and individual task defence preparation. Recommended number of hours allocated for the following work types preparation:

SIW types	Number of training hours
Classes preparation: lecture material studying, programs preliminary preparation for calculations in the class, reports on computer workshops preparation	2 - 3 hours a week
Individual task performance	10 hours
Individual task defence preparation	4 hours
Module test preparation	4 hours

Policy and control

7. The course/educational component policy

In face-to-face training mode, lectures and computer workshops are held in classrooms. In the blended mode, lectures are held through the e-learning platform Sikorsky, computer workshops - in the classrooms. In the remote mode, all classes are conducted through the e-learning platform Sikorsky.
At the beginning of each lecture, the lecturer can conduct a survey based on the materials of the previous lecture using interactive tools (Google Forms, menti.com, Kahoot, etc.). Before the next topic, the lecturer can send questions using interactive tools to determine the level of student's awareness on this topic, to increase interest and to engage students in solving practical tasks.

Rules of computer workshops and individual task defence:

1. *Несвоєчасні захист і виконання роботи без поважної причини штрафуються відповідно до правил призначення заохочувальних та штрафних балів.*

2. *Students who have performed the calculations correctly are allowed to defend (if the calculations are performed incorrectly, they should be re-calculated).*
3. *Defence takes place according to the schedule specified in item 5.*
4. *After checking the task, the teacher puts a total mark and the work is considered passed.*
5. *Untimely defence and performance of task without a valid reason are fined in accordance with the Rules of Bonus and Penalty Points.*

Rules of Bonus and Penalty Points:

1. *За активну роботу на лекції нараховується до 0,5 заохочувальних балів (але не більше 10 балів на семестр).*
2. *Late computer workshop performance without a valid reason is fined 1 point;*
3. *Untimely task defence without a valid reason is fined 1 point;*
4. *For each week of individual task delay is fined 1 penalty point (but not more than 5 points).*
5. *Task modernization is bonused at 1 - 6 points;*
6. *Teaching materials improvement is bonused at 1 - 6 points;*
7. *Up to 0.5 bonus points (but not more than 10 points per semester) are awarded for active work at the lecture.*

Policy of deadlines and retaking of a tasks/tests: determined by item 8 of the Regulations on Current, Calendar and Semester Control of Learning Outcomes at Igor Sikorsky KPI.

Academic Integrity Policy: determined by academic integrity policy and other provisions of the University's Code of Honour.

8. Types of control and rating system for learning outcomes evaluation (RSLOE)

Types of control are established in accordance with the Regulations on Current, Calendar and Semester Control of Learning Outcomes at Igor Sikorsky KPI:

1. *Ongoing control: surveys in computer workshops, module test, Individual task defence.*
2. *Calendar control: conducted twice a semester as a monitoring of the current state of compliance with the requirements of the syllabus.*
3. *Semester control: pass-fail test.*

Rating System For Learning Outcomes Evaluation

1. The student's course rating is calculated based on a 100-point scale, and consists of points that the student gets for:

- *work at computer workshops (6 tasks);*
- *module test (MT);*
- *individual task (IT);*
- *express control at lectures (7 answers).*

2. Scoring criteria:

2.1. Work at computer workshops:

At computer workshops, students acquire the ability to apply practical knowledge of process control systems by solving appropriately formulated problems. Before performing the practical task, the entrance control is carried out in order to determine the level of preparation for the lesson.

- *flawless work - 6 points;*
- *there are insignificant shortcomings in the preparation and / or performance of task - 5 points;*
- *there are shortcomings in the preparation and / or performance of task -4 points.*
- *task not performed or not defenced - 0 points.*

The maximum number of points for work at computer workshops is 36.

Preparation for lesson:

- *excellent preparation, complete answer to the questions of input control - 1 point;*

- *the presence of minor deficiencies in the answer to the question of input control (incomplete answer, but not less than 90% of the information) - 0.8 points;*
- *the presence of significant deficiencies in the answer to the question of input control (incomplete answer, but not less than 60% of information) - 0.5 points;*
- *the student could not answer the questions of input control - 0 points;*

Task performance:

- *the task is done completely and correctly within the allotted time - 3 points;*
- *the task is done almost completely and correctly within the allotted time or has unprincipled inaccuracies - 2 points;*
- *task performed more than half during the allotted time - 1 point;*
- *the task is done in the allotted time less than half, the results of the task contain gross errors, or task is absent - 0 points.*

Task defence::

- *the student correctly and completely performed all the tasks assigned to the defence (answered questions) - 2 points;*
- *the student correctly performed all the tasks provided for the defence, but made insignificant inaccuracies - 1.5 points;*
- *the student in performing the task (answers to questions) made a number of significant inaccuracies - 1 point;*
- *the student did not complete the task- 0 points.*

*2.2. **Module test:***

*Module test is estimated at **30** points; performance evaluation based on the following scale:*

- *complete answer (not less than 90% of the required information) - 27-30 points;*
- *sufficiently complete answer (not less than 75% of the required information), or complete answer with minor inaccuracies - 23 - 26 points;*
- *incomplete answer (not less than 60% of the required information) and minor errors - 18-22 points;*
- *unsatisfactory answer (does not meet the requirements for "satisfactory") - 0 points.*

*2.3. **Individual task**.*

Individual task is estimated at 20 points. Performance evaluation based on the following scale:

- *creative work, all requirements are met- 18 - 20 points;*
- *the task is performed with minor shortcomings, almost all the requirements for the task are met, or there are insignificant errors - 15 - 17 points;*
- *the work was performed with certain errors, there are shortcomings in meeting the requirements for the task and certain errors - 12 - 14 points;*
- *task is not credited (task not completed or there are gross errors) - 0 points.*

Individual task defence takes place at 15 weeks of training; the task should be submitted no later than one week before the defence.

*2.4. **Express control at lectures**.*

Express control is carried out in writing and bases at the lecture materials. The student receives one individual task at the end of the lecture, which is performed for 5 minutes. The of express control task is evaluated as follows:

2 points: the student correctly and completely completed the individual task;
1 point: the student has completed at least 75% of the individual task;
0 points: the student completed less than 60% of the individual task or was absent at the lecture during the express control.

Number of express surveys - 7. The maximum number of points that a student can receive for all answers is 14.

*3. The condition for obtaining a positive assessment of the calendar control is the implementation of all tasks planned for this time (for the time of the calendar control). At the **first calendar control** (8th week)*

*the student receives "credited" if his current rating is not less than 0.5·26[1] = 13 points. At the **second calendar control** (14th week) the student receives "credited" if his current rating is not less than 0.5·52[2] = 26 points and the calculation and graphic work is submitted for verification.*

The maximum number of points that a student can score during the semester is 100 points:

$$RC = r_{cw} + r_{mt} + r_{it} + r_{lec} = 36+30+20+14= 100 \text{ points}$$

To receive credit, a student must have a rating of at least 60 points, as well as enrolment in all computer workshops, MT, IT performance and defence. Students who have a rating of less than 60 points at the end of the semester, as well as those who want to increase the grade, perform a written final test and this score is final. The total mark of the course in this case is formed as follows: to the points that the student received for the IT, is added the points for the final test. The task of the final test consists of 6-8 tasks of varying complexity. Each question (task) is evaluated according to the following criteria:

- *"Excellent", complete error-free solution of the task -90 - 100%;*
- *"Good", complete solution of the task with insignificant inaccuracies - 70 - 80%;*
- *"Satisfactory", the task is performed with certain shortcomings - 55-60%;*
- *"Unsatisfactory", the task is not completed - 0 points.*

The maximum number of points for the final test - 80.

Correspondence table of rating points to grades on the university scale:

Scores	*Mark*
100-95	Excellent
94-85	Very Good
84-75	Good
74-65	Satisfactory
64-60	Enough
Less than 60	Unsatisfactorily
Admission conditions are not met	Not allowed

9. Additional information on the course/educational component

- *Requirements for Individual task registration, the list of module test and final test questions are given in Google Classroom " Advanced Process Control " (e-learning Sikorsky-distance platform).*
- *The list of materials and tools that are allowed to be used at the final test: computer workshop materials, table of basic Laplace functions, Mathcad mathematical package or similar.*

Syllabus is compiled by associate professors of the Department of Technology of Inorganic Substances, Water Treatment and General Chemical Technology:

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Ph.D. Olga Sanginova

Approved by the Department of Technology of Inorganic Substances, Water Treatment and General Chemical Technology (minutes # 19 of 30.06.2021).

Agreed by the Curricular Committee of the faculty (minutes # 10 of 23.06.2021).

[1] The maximum number of points that a student can score in 8 weeks.
[2] The maximum number of points that a student can score in 14 weeks.