UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

ERASMUS+

PROGRAMME CURRICULUM

for the academic year 2026/2027

Ljubljana, 2026

SUBJECTS FOR ERASMUS+ STUDENTS

Academic year 2026/27

WINTER SEMESTER	SUMMER SEMESTER
Engineering Design	
Design of Advanced Systems (6026-M)	Fatigue Design (6027-M)
Engineering Design Techniques (6024-M)	Geometric Product Specifications (6029-M)
Hydraulic Components and Systems (6030-M)	Nanotechnologies (6028-M)
Mechanics	
Dynamics of Machines and Structures (6038-M)	Advanced Dynamics (6035-M)
Mechanics of Structural Elements (6036-M)	FEM Structural Analysis (6037-M)
Rheology of Polymers (6042-M)	Mechanics of Light-Weight Structures (6040-M)
Mechatronics and Laser Technology	
Digital Control Technology (6054-M)	Advanced Sensory Systems and Networks (6062-M)
Laser Processing Technology (6061-M)	Manufacturing Automation (6063-M)
Robotic Systems - MAG (6055-M)	Photonics and Laser Sources (6059-M)
Production Engineering	
Additive Technologies (6052-M)	Advanced Forming Processes (6047-M)
CAM Systems (6051-M)	Heat Treatment (6046-M)
Smart Factories (6053-M)	Quality Engineering (6050-M)
Energy Engineering	
Energy Conversion Systems (6003-M)	Chemical Energy Carriers (6006-M)
Noise, Vibrations and Acoustic Engineering (6007-M)	Electromobility (6008-M)
Sustainable Sources of Electric Energy (6010-M)	Turbomachinery (6004-M)
Process Engineering	
Heat Exchangers (6020-M)	Air-conditioning, Heating, Refrigeration, Ventilation (6017-M)
Process Engineering (6021-M)	Computational Fluid Dynamics (6018-M)
Solar Utility Technologies (6016-M)	Refrigeration and Heat Pumps - MAG (6019-M)

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Design of Advanced Systems — 5 ECTS

Lecturer: **J. Klemenc, M. Nagode**

Lectures: 30h | Tutorials: 6h | Labs: 24h | Project: 0h | Lang. :

Objectives

1. To acquire a thorough insight in advanced design methods that enable consequent R&D processes of complex products.
2. To learn a thorough theoretical basics of selected statistical methods for product design.
3. To train approaches for solving design challenges in the case of random operating and environmental conditions.
4. To acquire skills of searching for additional design informations in the case of limited input data and/or informations.
5. To acquire team-work skills.

Programme

Prerequisites for design of complex systems. Effectiveness and value of product. Statistical analysis of complex systems (basics). Assuring the functional performance of a complex system. Failure modes and failure models for complex systems and their components. Design of advanced and complex systems. Product maintainability as a prerequisite for its availability. Case study of a R&D process for a complex high-series and low series products - selected topics from a passanger-car development process and from a development of an injectiom-molding tool.

Prerequisites

In order to successfully achieve this course, the students must have:

- Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

Knowledge:
Thorough theoretical, methodological and analyitical knowledge with elements of a research work that form a basis for very demanding professional work:

- Understanding a relationship between the operating conditions, environment and function of the complex product.
- Understanding a random nature of the product’s effectiveness and value.
- Understanding a theorethical background of the design methods for complex products that are based on a statistical approach.

Skills:
Mastering very demending and complex work processes and methodological tools in specialised professional fileds:

- Ability of analyitical and numerical prediction of the product’s operation in an unpredictable operating conditions.

Ability of unique innovations and critical reflections:

- Ability of research in the field of the complex-product effectiveness

Assessment

- Theoretical knowledge (written colloquia and exam with an optional oral examination): 50%,
- Auditorial exercises (seminar reports with presentations): 30%,
- Written examination of practical knowledge that was acquired in exercises: 20%.

Literature

1. Ebeling C.E. An introduction to reliability and maintainability engineering – 2nd edition. Waveland press inc., 2010.
2. Andrews J.D., Moss T.R. Reliability and risk assessment - 2nd edition. John Wiley & Sons, 2002.
3. Pahl G., Beitz W., Feldhusen J., Grote K.H. Engineering Design - A Systematic Approach. Springer Verlag, 2007
4. Part and Mold Design - A Design Guide. Bayer Corporation, 2000.

Engineering Design Techniques 5 ECTS

Lecturer: **L. Kos, N. Vukašinović, I. Demšar**

Lectures: 30h | Tutorials: 8h | Labs: 22h | Project: 0h | | Lang. :

Objectives

- to learn about different approaches / models in product development at different levels of design,
- to learn what methods and tools to use in different phases of product development,
- to become familiar with characteristics of different design method and how to use them,
- and to consider the following approaches in the product development process: legislation, environment, costs, robustness, innovation, IT support.

Programme

The course introduces methods and tools for a systematic approach to product development and design of complex systems.
Course starts with the whole life cycle of the product and on the growth and maturity curve of the products. It is necessary to have the product in mind, from eco design, manufacturing, use, maintenance, to recycling. The entire life cycle of the product needs to be considered at the design stage. Several methods have been developed for a comprehensive approach to design: concurrent development, development for six sigma, quality requirements in the automotive industry, verification, and validation of prototypes. The aim is to develop a systemic mindset that is necessary in the design of products using methods such as TRIZ, APQP, FMEA, DFSS, SPC, MSA, DoE, ANOVA, etc. An important part of the content is dedicated to legislation that must be followed by any manufacturer who wants to sell the product on the market. An overview is given of the requirements and rules to be followed in the intellectual property. Particular attention is given to product safety and harmonised standards which constitute minimum requirements for the European market. Project work and product development is inextricably linked to the management of technical documentation. Knowledge of technical information systems (PLM) is of particular importance in complex and spatially distributed projects. Finally, methods for data modelling of processes and products are systematically presented.

Prerequisites

To successfully achieve this course, the students must have fundamental knowledge in:
- Engineering design methodology
- Machine elements 1, 2
- Technical drawing and 3D modelling

Learning outcomes

The student acquires in-depth theoretical, methodological and analytical knowledge of methods of engineering design techniques with elements of research, which is the basis for a comprehensive approach to the development of products at different levels of design.

The students will gain proficiency in complex work processes and methodological tools in the field of engineering design:
- Independent solving of technical problems in mechanical engineering.
- Capable of teamwork and interdisciplinary cooperation.

Planning and managing a workflow based on creative problem solving related to the field of engineering design:
- Ability to apply modern methods and procedures and ability to transfer of theoretical knowledge into practice.

Assessment

Theoretical content (lectures). 50%
Project work (excercises). 50%

Literature

1. K.T. Ulrich and S.D. Eppinger, Product Design and Development, Irwin McGraw-Hill, 2020
2. E. B. Magrab, S.K. Gupta, F.P. McCluskey, P. A. Sandborn, Integrated Product and Process Design and Development, The Product Realization Process, Taylor & Francis Group
3. G. Pahl, W. Beitz, J. Feldhusen, K.H. Grote, (2007), Engineering design, A Systematic Approach, Third Edition, Springer

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Hydraulic Components and Systems 5 ECTS

Lecturer: **F. Majdič**

Lectures: 30 h | Tutorials: 14 h | Labs: 12 h | Project: 4 h | Lang. :

Objectives

1. To acquire advanced knowledge in the field of development and research of new hydraulic components.
2. To acquire advanced knowledge for the calculation of transient phenomena within hydraulic systems.
3. To acquire knowledge in the design of hydrostatic drives in closed circuits.
4. Expanding knowledge in the field of modern controlled hydraulic pumps and motors.
5. Know how to use proportional, digital and servo valves.
6. To know how to design hydraulic component and to use topological optimisation
7. To know how to do numerical calculations of hydraulic components and systems.

Programme

1. Transient phenomena in hydraulic systems.
2. Hydrostatic actuators in a closed circuit.
3. Hydraulic control of the direction of travel of mobile machines.
4. Advanced control and regulation of variable displacement pumps.
5. Design and development of new hydraulic components.
6. Electro-hydraulic control, proportional, servo and digital valves and controls.
7. Diagnostics of hydraulic systems.
8. Numerical calculations - simulations of hydraulic components in a three-dimensional system.
9. Simulations of hydraulic systems.
10. Current trends and guidance in the development of hydraulic components and systems.

Prerequisites

In order to successfully achieve this course, the students must have:

- Basic knowledge of hydraulics and pneumatics
- Basic knowledge of physics

Learning outcomes

Knowledge: In-depth theoretical, methodological and analytical knowledge of hydraulic components, their operation and synthesis of knowledge in the development and research of new hydraulic components and in the construction of complex hydraulic systems.
Skills:

- Mastering highly complex, complex work processes and methodological tools in the design of new hydraulic components and systems.
- Design and control of the design, calculation, measurement, installation and test run of a new hydraulic component and / or the entire system based on creative problem solving.
- Ability to reflect critically and original knowledge of hydraulic components and systems - new patents, products, devices and / or scientific articles.

Assessment

- A theoretical content (lectures): 50%,
- Independent work in exercises: 20%,
- Independent work in lab work (reports and assessment): 15%,
- Seminar: 15%.

Literature

- Matthies, H.J.: Renius, K.T.: Einführung in die Ölhydraulik, Teubner Verlag, 2003.
- D. Findeisen, S. Helduser, Ölhydraulik: Handbuch der hydraulischen Antriebe und Steuerungen, 6. Auflage, Springer Verlag, 2015
- J. L. Johnson: Basic electronics for hydraulic motion control, Penton Publishing Inc., 1992.
- H. Murrenhoff, H. Wallentowitz, Fluidtechnik für mobile Anwendungen, 3. Auflage 2006, RWTH Aachen, Schaker Verlag, Aachen

Fatigue Design — 5 ECTS

Lecturer: **M. Nagode, J. Klemenc, D. Šeruga**

Lectures: 30h | Tutorials: 6h | Labs: 24h | Project: 0h | | Lang. :

Objectives

1. Gain knowledge of damage of crystal lattice due to cyclic and monotonous loading.
2. Gain knowledge of the damage growth process and the influences to this process.
3. Gain knowledge and understand high cycle and low cycle fatigue, fatigue crack growth and learn to use associated methods and computer software on practical examples.
4. Upgrade fundamental knowledge of mechanical engineering and use it on practical examples.

Programme

Introduction into operational strength. Defects in crystalline solid. Crack growth propagation. High cycle fatigue - Region of validity determination. High cycle fatigue - SN curve and hypothesis on damage accumulation and damage evolution. High cycle fatigue - Equivalent stress amplitude. High cycle fatigue - Damage calculation for random load history: conventional and alternative procedure. Low cycle fatigue - Region of validity determination and influence of macro yielding. Low cycle fatigue - Stress - strain response: conventional and alternative procedure. Low cycle fatigue - EN curve and damage parameters. Low cycle fatigue - Damage calculation for random load history: conventional and alternative procedure. Cyclic creep and relaxation.

Prerequisites

In order to successfully achieve this course, the students must have:

- Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

Knowledge:
In-depth theoretical, methodological and analytical knowledge with elements of research, which is fundamental for very demanding professional tasks:

- Understanding and mastering mechanisms that lead to damage due to cyclic and monotonous loading.
- Mastering methods to predict durability due to high cycle and load-cycle fatigue and creep.
- Understanding and mastering methods to predict fatigue crack growth.

Skills:
Mastering very demanding and complex work processes and methodological tools in specialised fields:

- high cycle and low cycle fatigue and creep and fatigue crack growth.

Ability of original breakthroughs/creations and critical reflection in the field of operational strength.

Assessment

- Theoretical knowledge (lectures): 50%,
- Individual work at exercises: 20%,
- Work at laboratory exercises (including reports): 20%,
- Seminar: 10%.

Literature

1. Dowling N.E., Kampe S.L., et al. Mechanical Behavior of Materials - Fifth Edition. NE. Pearson Education Limited, 2018.
2. Lemaitre J., Desmorat R. Engineering Damage Mechanics: Ductile, Creep, Fatigue and Brittle Failures. Springer Vieweg, 2005.
3. Wu X. Deformation and Evolution of Life in Crystalline Materials: An Integrated Creep-Fatigue Theory. CRC Press, 2019.
4. Naumenko K., Altenbach H. Modeling High Temperature Materials Behavior for Structural Analysis: Part II. Solution Procedures and Structural Analysis Examples (Advanced Structured Materials Book 112). Springer, 2019.

Geometric Product Specifications 5 ECTS

Lecturer: **R. Kunc, S. Zupan**

Lectures: 30h	Tutorials: 22h	Labs: 8h	Project: 0h	Lang. :

Objectives

1. Gaining theoretical and practical knowledge in the field of detailed geometrical product specifications (GPS).
2. Understanding principles and rules of standardized Geometrical Dimensioning and Tolerancing (GDT) systems and their practical use.
3. Understanding statistical geometrical tolerances and statistical control of production processes and practical use.
4. Understanding and developing geometrical tolerance analyses (TA) and practical use.
5. Understanding and development of specialized software tools (GPS, GDT, TA).

Programme

Lectures :

Introduction and basic definitions of GPS according to ISO standards. General GPS principles and rules, specifications on virtual (3D) models and on technical drawings (2D).
What is Geometrical dimensioning and tolerancing (GDT) and why to use it. Datums and datum systems (i.e. references). Geometrical tolerances (GT) definitions and practical use – form, orientation and location tolerances. Runout and Profile geometrical tolerances. Material conditions of GT, meaning and use.
Methods of geometrical tolerance (GT) verification and tolerance analyses (TA). Statistical tolerances (ST). State of technical surfaces and edges. Adding GPS in 3D virtual models (Model Based Definition) and transmission into technical documentation (2D). Product Data Management (PDM) and Product Lifecycle Management (PLM) systems and software…

Prerequisites

In order to successfully achieve this course, the students must have:
Meeting the enrolment conditions for the Master's study program of Mechanical Engineering - Research and Development program.

Learning outcomes

After attending this course, the student will get in-depth theoretical, methodological and analytical knowledge with elements of research, which is the basis for demanding specialist work skills:

- Know how to interpret complex technical drawings and 3D models with added GPS symbol information and produce complex technical drawings and complete 3D models with standardized symbols and indications/attributes. Know and understand complex concepts and rules of tolerancing (GDT) and surface and edges states marking.
- Understand and know how to use theoretical backgrounds and methods for conducting linear geometrical tolerance analyses (TA) and understand and know how to use software tools for complex spatial tolerance analyses.
- Understand the role and meaning of complex rules of technical documentation and the importance of those rules for functionality.

Assessment

- Theory examination (written/oral): 50%,
- Practical examination in laboratory (written/oral): 20%,
- Project (home) work (written): 30%.

Literature

1. Henrik S. Nielsen, The ISO Geometrical Product Specifications Handbook (2nd ed.), ISO/Danish Standards 2024, ISBN: 978-92-67-11040-4 (print), ISBN: 978-92-67-11041-1 (PDF-DRM)
2. Stefano Tornincasa, Technical Drawing for Product Design, Mastering ISO GPS and ASME GD&T, 1st ed. 2021, Springer, ISBN 978-3-030-60853-8, e-ISBN 978-3-030-60854-5
Additional:
3. ZUPAN, Samo, KUNC, Robert, ŽEROVNIK Andrej.: Geometric Product Specifications (GPS); Geometric Tolerances (definitions) and analyses (GTA); study material (subject online classroom) / university textbook in preparation (SLO / EN language)

Nanotechnologies 5 ECTS

Lecturer: **M. Kalin**

Lectures: 30h | Tutorials: 12h | Labs: 18h | Project: 0h | Lang. :

Objectives

1. To understand basic scientific and applied problems at the nano scale and enable creative ability to tackle them.
2. To learn about different nanotechnologies and their application and limitations.
3. Understand the fundamental physical principles at the nano level.
4. To learn and understand the basic principles and application of nanostructures and nanomaterials.

Programme

Lectures:

1. Introduction: definitions, examples, field of work, history.
2. Characteristics of nanotechnologies and specifics of nano scale phenomena: differences between nano and macro technology. Minituarization, physical laws, fundamentals of quantum mechanics, electromagnetic waves, quantization of energy, duality of energy and matter, the principle of indeterminacy.
3. Bonds and surface forces: classification and properties of bonds, intramolecular bonds, Lennard-Jones potential, van der Waals bonds. Surface forces between bodies - key equations. Forces in fluids: electrostatic, zeta potential, DLVO theory, structural forces (solvation, hydration, hydrophobic).
4. Free surface energy and wettability: surface energy, surface tension. Wettability, Young's equation, types of wettability, influences (Cassie, Wenzel, homogeneity, chemical). Capillary effect and condensation, meniscus.
5. Adhesion and adsorption: adhesion work, adhesion between solids and in moisture. Adsorption, adsorption types, isotherms. Surface film growth.
6. Characterization of nanostructures: optical methods, electron microscopy, scanning probe methods, spectroscopic methods, diffraction, combined methods.
7. Nanomaterials production: types, fabrication, bottom-up growth (ALD, sol-gel, SAM, chemical, ...) and top-down (crushing, multiple types of lithography).
8. Types of nanomaterials: basic differences and characteristics, types: nanoparticles, nanofilms, nanograins, nanoporous, nanowires, nanotubes, fullerenes, graphene ...
9. Nanoscience: health dangers in nanotechnology, measurements, legislation, protection.
10. Surface effects and nanotubes: nano surface Properties, real surface, nanotubes, models, nanocontacts. Super-low friction with solids.
11. Thin-film lubrication: nanotubes, thin-film lubrication, thin-film lubrication concepts. Super-low friction with liquids.
    Nanotribology in engineering systems: examples of nanotribology application. Boundry lubrication in engines, in cutting and forming processes. Boundary slip, slip length, calculation models.
12. Nano-scale modeling: application of nano-scale modeling: first principles and molecular dynamics.
13. Nanotechnology for tribological solutions (Brainstorming): system analysis, possibilities, concepts, measurements, implementation, solutions, application. Example.
14. Application of nanotechnologies in technology: nanotechnology, nanobiotechnology, nanosensors, nanomechanics, nanotechnologies in batteries, healthcare, automotive, MEMS/NEMS, optics, textiles.

Prerequisites

In order to successfully achieve this course, the students must have:

- Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

Knowledge:
In-depth theoretical, methodological and analytical knowledge with elements of research and application in nanotechnology.

Skills:

- Understanding the procedures and applications of nanotechnologies.
- Independent evaluation and analysis of nanostructures and nanomaterials.
- Ability to perform basic physical nano-level modelling and experimental techniques with rigorous analyses of results.

Assessment

Theoretical subject (lectures): 50%, Independent work in tutorials: 20%, Laboratory work in tutorials (including reports): 20%, Seminar: 10%.

Literature

1. L.Theodore: Nanotechnology - Basic Calculatuions for Engineers and Scientists, Wiley-Interscience, 2006.
2. B. Rogers, J. Adams, S. Pennathur: Nanotechnology - Understanding small systems, CRC Press, 2008.
3. B. Bhushan (Ed): Handbook of Nanotechnology, Springer, 2007.

Dynamic of Machines and Structures 5 ECTS

Lecturer: **G. Čepon**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 65h | | Lang. :

Objectives

The objective of this course is to provide students with advanced knowledge of the dynamics of machines and structures, with emphasis on numerical and analytical modelling of dynamic systems. The course aims to develop a deep understanding of elasto-dynamic behaviour of continuous and discrete systems, modal analysis, damping, and dynamic response of complex mechanical systems. Special focus is placed on the finite element method (FEM), dynamics of rotating machinery, and dynamic modelling of robotic systems, enabling students to apply advanced dynamic techniques to real engineering problems.
The course will cover:

- Fundamentals of machine and structural dynamics and system discretization
- Elasto-dynamic formulation and numerical approximation methods
- Finite element modelling, modal analysis, reduction, and damping
- Dynamics of rotating machinery and mechanical components
- Dynamics and modelling of robotic and flexible multibody systems

Programme

- Fundamentals of machine and structural dynamics, including discretization and elasto-dynamic formulation of continuous systems
- Numerical methods for dynamic analysis, including Rayleigh–Ritz approximation, modal analysis, and eigenvalue problems
- Finite element method in linear dynamics, modal superposition, model reduction, and damping modelling
- Dynamics of mechanical systems and machinery, including belt drives, rotors, flexible rotors, bearings, and piston machinery
- Dynamics of robotic and flexible multibody systems and application of the presented methods to real engineering structures

Prerequisites

To successfully complete this course, students should have:

- Good knowledge of engineering mechanics
- Basic understanding of dynamics and mechanical vibrations
- Fundamental knowledge of differential equations and linear algebra

Learning outcomes

After attending this course, the student will:

- Develop analytical and finite element models for dynamic analysis of machines and structures
- Analyse dynamic response and vibration behaviour of mechanical and structural systems
- Perform modal analysis, damping modelling, and model reduction
- Evaluate dynamics of rotating machinery and robotic systems
- Apply advanced dynamic analysis methods to real engineering problems

Assessment

- Written examinations (mid-term tests and final exam)
- Laboratory work and written reports

Literature

- Rao, S. S. *Mechanical Vibrations*, 5th ed., Addison-Wesley Publishing Company, 2011.
- Maia, N. M. M., Silva, J. M. M. *Theoretical and Experimental Modal Analysis*, Research Studies Press, 1997.
- Craig, R., Kurdila, A. *Fundamentals of Structural Dynamics*, Wiley, 2006.

Mechanics of Structural Elements 5 ECTS

Lecturer: **M. Halilovič**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 65h | | Lang. :

Objectives

The objectives of this course are to learn mathematical formulations of theories in the field of mechanics for structural analysis, to learn the procedures of mechanical analyses of structural elements (trusses, beams, shafts, plates, shells), mastery the skills of treating real construction with mathematical models, which requires critical thinking on the idealization of structures and the synthesis of individual theories. With this course student will get the following competences:

- mastering the advanced theoretical knowledge used for analytical or numerical mechanical analysis of structures,
- the ability to perform advanced analytical and numerical analysis of frame and plane structures,
- the ability to analyse problems critically and analytically through the study of advanced theories in mechanics.

Programme

The aim of the course is to characterize the mechanical response of structural elements and present the calculation methods for determining their response. Namely, calculations of real constructions are normally performed by decomposing a construction into several structural elements. In this process, certain assumptions need to be adopted and it is crucial that all assumptions are valid for the elaborated case. We will study basic theories of structural mechanics and present typical examples of individual structural elements. The course covers the following topics: basics of continuum mechanics (displacements, strains, stresses), a definition of the boundary value problem in elastostatics (a problem domain, basic equations and boundary conditions), a definition of structural elements according to their geometric dimension (frame, plane and three-dimensional structures) and according to their curvature (straight/curved beams, plate/wall/ shell). We will present the theoretical background of frame elements, shafts, membranes, plates and shells, and discuss the mechanical response that is provided by different theories, e.g. Bernoulli/Timoshenko, Kirchhoff/Mindlin-Reissner etc. We will also learn how to compute the response of structural elements using analytical and numerical methods (the finite difference and the finite element methods). All computations will be performed in Wolfram Mathematica. We will also present the concept of geometrical symmetry and structure periodicity – axial and planar symmetry, and planar and cyclic periodicity; the referential subdomain concept; the division of external loads to the symmetric and the antisymmetric part; present the properties of vector and tensor response fields for the symmetric/asymmetric and periodic load case.

Prerequisites

No conditions.

Learning outcomes

In-depth theoretical knowledge of analysing different structures. Knowledge of advance numerical techniques such as finite element method for solving 1-d and 2-d structural problems. Analytical knowledge to understand and perform mechanical analysis independently.

- Performing complex mechanical analysis of 1-d and plane structures
- The ability to synthesize acquired knowledge to examples of real structures
- The ability to critically analyse results and evaluate their validity

Assessment

- 50% Theory
- 30% Practical work
- 20% Coursework

Literature

- Hartmann: The Mathematical Foundation of Structural Mechanics, Springer-Verlag, 1985.
- Armenakas: Clasical Structural Analysis – A Modern Approach, McGraw-Hill, 1988.
- Young, Budynas: Roark's Formulas for Stress and Strain, McGraw-Hill, 2012

Rheology of polymers 5 ECTS

Lecturer: **L. Slemenik Perše**

Lectures: 30h | Tutorials: 18h | Labs: 12h | Project: 65h | Lang. :

Objectives

The objectives of the course are to understand the importance of rheology for polymer materials, determination of rheological properties and interpretation of the obtained results, to learn about the importance of rheological properties in mechanical engineering and R&D. With this course student will get the following competences:

- application of rheological properties for polymer products,
- the ability to analyse the experimental results of rheological tests,
- the ability to apply rheological properties in special process applications,
- the ability to use rheological properties in R&D,
- the ability to analyse the published scientific results.

Programme

- INTRODUCTION: Basic rheological parameters, Material functions in time and frequency domain, Flow regimes, Effect of molecular weight on mechanical and rheological properties
- RHEOMETRY: Instruments, Sensor systems, Methods, Analysis
- YIELD STRESS: Engineering examples, Equations for rheological behaviour of materials with yield stress, Determination and prediction of the behaviour of polymers with yields stress
- VISCOELASTICITY: Creep and relaxation, Energy absorption, Mechanical models, Explanation of general stress-strain state of viscoelastic materials using material functions
- LINEAR THEORY of VISCOELASTICITY: Linear and non-linear behaviour of materials, Practical meaning of linear theory of viscoelasticity, Determination of stress limit
- TIME DEPEDENCY: Relaxation time, Thixotropy, Physical aging, Mechanical spectra
- EFFECT of TEMPERATURE: Temperature tests, Phase transitions, Degradation
- RHEOLOGICAL PROPERTIES of POLYMERS in RESEARCH and DESIGN: polymer processing (Dye swell effect, Weisenberg effect, melt fracture, yield stress), time dependent properties and life-time of polymer products (gears, seals, valves, ...)
- SPECIAL APPLICATIONS of RHEOLOGICAL PROPERTIES of POLYMERS in MECHANICAL ENGINEERING: Thixotropy, Tribology, Life-time assessment of different polymer products for various applications (ferro and magneto-rheological, chromogenic materials, self-healing polymers, …)

Prerequisites

Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

In-depth theoretical and practical knowledge of rheological properties of polymers in mechanical engineering applications.

- Preparation of basic methods for determination of rheological properties of polymers.
- Application of various rheological methods for prediction and interpretation of rheological behaviour of polymers in real process applications.

Assessment

- 40% Theoretical part (lectures), 30% Individual work during laboratory practice, 30% Laboratory work (report included)

Literature

- Shaw M.T.: Introduction to Polymer Rheology, John Wiley & Sons, 2012
- Ferry J.D.: Viscoelastic Properties of Polymers, John Wiley & Sons, 1980
- Osswald T.A., Rudolph N.: Polymer Rheology Fundamentals and Applications, Hanser Publishers, 2014

Advanced Dynamics 5 ECTS

Lecturer: **G. Čepon, J. Slavič**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 65h | Lang. :

Objectives

The objective of this course is to provide students with advanced knowledge of mechanical vibrations and system dynamics, with an emphasis on analytical modelling, physical interpretation of dynamic phenomena, and practical engineering applications. The course aims to deepen the understanding of dynamic response of single- and multi-degree-of-freedom systems subjected to various types of excitation. Special attention is given to experimental methods, vibration testing, and modern optical measurement techniques.

The course will cover:

- Fundamental principles of analytical statics and dynamics
- Dynamic response of systems under periodic and impulsive excitation
- Dynamics of systems with multiple degrees of freedom
- Vibrations of continuous systems
- Practical and experimental aspects of higher dynamics

Programme

- Fundamentals of analytical statics and dynamics: Introduction to analytical modelling and dynamic behaviour of mechanical systems.
- Dynamic response of systems to external excitation: Analysis of system response to periodic and impulsive loading.
- Dynamics of multi-degree-of-freedom systems: Modelling and analysis of mechanical systems with multiple degrees of freedom.
- Vibrations of continuous mechanical systems: Study of vibrations in strings, shafts, and beams.
- Advanced and experimental topics in dynamics: Engineering applications, optical vibration measurement techniques, and nonlinear dynamics.

Prerequisites

To successfully complete this course, students should have:

- Good knowledge of engineering mechanics
- Basic knowledge of dynamics and vibrations
- Basic knowledge of differential equations and linear algebra

Learning outcomes

After attending this course, the student will:

- Understand and analytically model mechanical vibration problems
- Analyse the dynamic response of systems subjected to different types of excitation
- Model and interpret the behaviour of multi-degree-of-freedom systems
- Analyse vibrations of continuous systems such as strings, shafts, and beams
- Understand experimental and optical methods for vibration measurement
- Apply advanced dynamic concepts to practical engineering problem

Assessment

- Written examinations (mid-term tests and final exam)*
- Laboratory work and reports

Literature

- Rao, S. S., *Mechanical Vibrations*, 6th ed., Pearson, 2019.
- Thomson, W. T., Dahleh, M. D., *Theory of Vibration with Applications*, Pearson, 1997.
- Meirovitch, L., *Methods of Analytical Dynamics*, Dover Publications, 2010.

FEM Structural Analysis — 5 ECTS

Lecturer: **M. Halilovič, B. Starman**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 65h | Lang. :

Objectives

The objectives of this course are to provide students with a solid understanding of the theoretical background of various types of finite elements used in the computer-based structural analysis. The course also develops student's ability to create appropriate numerical models of structures and to define relevant loading conditions. Furthermore, students acquire the skills needed to present and critically evaluate the results of numerical analysis. Upon completion of this course, students will be able to:

- understand the theoretical foundation of FEM and develop own program codes;
- create optimal numerical models of structures,
- present and analyse of results, considering the characteristics of the finite elements and the physical problem.

Programme

- Fundamentals of modelling of structures.
- Numerical modelling: comparison of numerical methods in terms of suitability for structural analysis, fulfilment of boundary conditions, basic steps in FE analysis.
- Steps in FE analysis.
- Properties of FEs, determination of initial, boundary and loading conditions.
- Isoparametric FE: interpolation functions, mapping to a natural coordinate system, mapping to a volume coordinate system, Gaussian quadrature rule.
- 3D FE to solve thermal or mechanical problems: determination of the number of FE DOF, point load, area distributed load, volume distributed load, analysis of the results.
- Axisymmetric FE to solve thermal or mechanical problems: mapping from Cartesian to cylindrical coordinate system, conditions for use of axisymmetric Fes.
- 2D FE to solve thermal or mechanical problems: conditions for the use of 2D FEs.
- Shell FE to solve shell structure problems; conditions for the use of shell FEs.
- 1D FE: matrix form of the system of linear equations in case of axial loaded construction elements, matrix form of the system of linear equations in case of Euler-Bernoulli theory and Timoshenko beam theory of bending beams, types of loads, visualization and analysis of the results.
- Advanced use of FEM: mirror symmetry, antisymmetry, cyclic symmetry, periodic boundary conditions, connection of different types of FEs

Prerequisites

- No conditions.

Learning outcomes

- In-depth knowledge of FEM theory and methodology, with ability to implement it in custom program codes for modelling complex physical problems.
- Mastering efficient computer-aided FEM of structures, with the ability to critically analyse and interpret results.

Assessment

- 50% Theory; 30% Practical work; 20% Coursework

Literature

- "The Finite Element Method for Solid and Structural Mechanics" - Elsevier - O.C. Zienkiewicz, R.L. Tayler, D.D. Fox, 2014
- "The Finite Element Method: A practical course" - Elsevier - G.R. Liu, S.S. Quek, 2014
- "Structural Analysis with the Finite Element Method Linear Statics", Springer - E. Onate, 2013

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Mechanics of Light-weight Structures — 5 ECTS

Lecturer: **M. Brojan**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 65h | Lang. :

Objectives

This course provides a comprehensive foundation in the principles of lightweight (LW) structural design and efficient material use. It begins with an experimental, theoretical, and numerical investigation of layered and fiber-reinforced composite materials. Structural optimization is introduced to their minimize weight. Because LW structures are typically thin or incorporate such elements, a major focus of the course is the analysis of stability and the prevention of buckling. Beyond failure avoidance, the course introduces concepts from nonlinear mechanics to demonstrate how structural instabilities can be deliberately exploited to achieve advanced and novel functionality.

Upon completion of the course, students will have developed the following competencies:

- the ability to design and optimize lightweight structures for efficient material use,
- the ability to analyze and prevent failure in lightweight structures due to loss of stability and other mechanisms,

Programme

Part I: Materials and Optimization for Lightweight (LW) Design

- **Introduction:** Basics of LW structures; efficient material use and favourable stress distribution.
- **Weight Optimization of Layered Materials & Fibre-reinforced Composites:** Practical laboratory work, design principles, theory and numerical analysis of thin-skin and fiber-reinforced structures.
- **Formal Optimization Methods:** Definition of an optimization problem (objective function, design variables, equality/inequality constraints, Karush-Kuhn-Tucker conditions); application to thickness optimization and improving the load-carrying capacity of classical and composite structures.
- **Applied Project:** Optimization of a composite beam (working example: a composite aircraft wing).

Part II: Stability of Slender Structural Elements

- **Review and Challenges:** Slender elements (beams, plates, shells) in composite structures; problems in application (discontinuities, nonlinearities, imperfections, interaction effects).
- **Basic Stability Concepts:** Stability; limit load and bifurcation buckling; theory and experiments.
- **Buckling of Beams:** Physically correct equilibrium on a deformed beam; influence of imperfections; buckling under self-weight; beams on discrete elastic supports and elastic foundations (wrinkling);
- **Buckling of Plates and Shells:** Experimental and theoretical exploration of critical buckling forces for plates and shells; experiments and theory of wrinkling of composite plates.

Prerequisites

Enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

Thorough professional theoretical and practical in a selected field of expertise that is supported with a broad theoretical and methodological basis. Be aware of the benefits and requirements of process modelling:

- In-depth knowledge of design principles for making LW structures and optimization.
- In-depth knowledge of nonlinear response of structural elements and solution methods for the design of LW structures

Assessment

20 % Examination (lectures - theory)
60 % Examination (exercises – design calculations)
10 % Laboratory exercises
10 % Homework

Literature

S.P. Timoshenko, J.M. Gere: Theory of Elastic Stability
G. Simitses & D.H. Hodges: Fundamentals of Structural Stability
J.M.T. Thompson & G. W. Hunt: General Theory of Elastic Stability
J. Singer, J. Arbocz, T. Weller: Basic Concepts, Columns, Beams and Plates (Volume 1 & 2)
D. Bigoni: Nonlinear Solid Mechanics - Bifurcation Theory and Material
Z.P. Bazant, L. Cedolin: Stability of Structures: Elastic, Inelastic, Fracture, and Damage Theories

Digital Control Technology — 5 ECTS

Lecturer: D. Kozjek, G. Škulj

Lectures: 30h | Tutorials: 12h | Labs: 18h | Project: 0h | Lang. :

Objectives

- To learn the structure and operation of modern digital platforms (microcontrollers, embedded computers, FPGA circuits) and the possibilities of their use in mechatronics and control systems, to understand their capabilities and specifications.
- To learn the methods and procedures of hardware development for control applications based on microcontrollers, embedded computers, and FPGA circuits with particular emphasis on an interdisciplinary approach.
- To learn the methods and procedures for the development of controller software for microcontrollers.

Programme

1. Introduction, Course Overview
2. Digital integrated circuits
3. Sequential Logic Systems, Microprocessor, and Microcontroller
4. Microcontroller architectures
5. Power interfaces
6. Digital IO, counters and timers
7. AD and DA converters
8. Interrupt system
9. Serial communications with microcontrollers
10. Standard buses in microcontroller applications
11. Low power microcontroller applications
12. Operating systems for real-time processing (RTOS, FreeRTOS)
13. Embedded computer and Linux
14. FPGA circuits

Prerequisites

It is good to have the following knowledge and skills before the start of this course:

- Basic knowledge about electricity
- Knowledge and understanding of the operation of basic electronic components (resistor, diode, switch, transistor, capacitor, etc.)

Learning outcomes

After attending this course, the student will obtain the following knowledge/skills:

- In-depth theoretical, methodological and analytical knowledge on applications of microcontrollers and other digital control circuits in mechatronics, which is the basis for demanding professional work and enables the carrying out of leading tasks in interdisciplinary development teams in the field of mechatronics.
- Mastering highly comprehensive, complex workflows and methodological tools in the field of mechatronics.
- Design and manage workflows based on creative problem solving related to mechatronics.

Assessment

50% Theoretical exam, 50% Laboratory work

Literature

1. Alvano J. Embedded Systems: Real-Time Operating Systems for Arm Cortex M Microcontrollers – 2nd edition. CreateSpace Independent Publishing Platform, 2012.
2. Johnson A. More to C - Advanced Programming with C in Linux and on Raspberry Pi – 1st edition. CreateSpace Independent Publishing Platform, 2017.
3. Monk S. Programming FPGAs: Getting Started with Verilog – 1st edition. McGraw-Hill Education TAB, 2016.

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Laser Processing Technology 5 ECTS

Lecturer: **P. Gregorčič, M. Jezeršek**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 0h | Lang. :

Objectives

The objectives of this course are to provide students with fundamental and advanced knowledge of modern laser processing technologies and to enable them to analyse, model, and optimise laser-based manufacturing processes. Through a combination of lectures, theoretical exercises, and laboratory work, students gain both theoretical understanding and practical experience with key laser processing techniques.
The objectives of this course are to:

- understand the physical principles of laser operation;
- understand the role of laser system components;
- understand the fundamental mechanisms of laser–matter interaction;
- understand the influence of laser and process parameters on processing efficiency and quality;
- acquire practical experience with selected laser processing techniques, including laser safety, engraving, drilling, welding, cutting, and ultrashort-pulse laser ablation of metals;
- acquire practical experience with basic methods for monitoring and control of laser processing processes.

Programme

1. Introduction – wider context of laser processing
2. Basics of lasers
3. Laser processing systems
4. Interaction between laser light and matter
5. Conversion of optical energy into thermal energy
6. Laser drilling – modelling with a Gaussian beam
7. Laser surface engineering
8. Laboratory work: laser safety, laser engraving, laser drilling, laser welding, laser cutting, and ablation of metals by ultrashort laser pulses

Prerequisites

In order to successfully attend this course, students are expected to have:

- Basic knowledge of optics and the physics of light
- Elementary mathematics (including basic calculus)
- Basic concepts of physics related to thermal properties of materials

Learning outcomes

After attending this course, the student will obtain the following knowledge and skills:

- thorough theoretical, methodological, and analytical knowledge with elements of a research work, forming a basis for demanding professional work in the field of laser processing and laser-based manufacturing technologies;
- the ability to plan, analyse, and manage laser processing tasks on the basis of creative problem solving, including the selection of appropriate laser systems and processing parameters, supported by practical laboratory training

Assessment

33% theory, 33% theoretical problem solving, 33% laboratory work

Literature

1. W.M. Steen, Laser Material Processing (4th Edition), Springer Verlag, 2010
2. E. Kannatey-Asibu, Principles of laser materials processing, John Wiley & Sons, 2009
3. J.F.Ready, Industrial Applications of Lasers, 2nd. ed., Academic Press, 1997
4. D. Schuoecker, High Power Lasers in Production Engineering, Imperial College Press, 1999.
5. M. Zupančič, P. Gregorčič, Laser Surface Engineering for Boiling Heat Transfer Applications, Springer International Publishing, 2021, pp. 245-303
6. P. Gregorčič, L. Hribar, Laser processing technology: theoretical exercises with solutions, Ljubljana, 2024.

Robotic Systems 5 ECTS

Lecturer: **R. Vrabič**

Lectures: 30h | Tutorials: 12h | Labs: 18h | Project: 0h | | Lang. :

Objectives

The objectives of this course are to provide students with a comprehensive understanding of robotic systems and their industrial applications. In an era of increasing automation and smart manufacturing, robotics plays a central role in modern industry. This course equips students with the theoretical foundations and practical skills necessary to design, program, and integrate robotic systems.
The course covers:

- Understanding of all types of industrial robots, including articulated robot arms and autonomous mobile robots
- Control, programming, and development of custom robotic applications
- Integration of industrial robots with other manufacturing systems
- Software and hardware interfaces in robotics, including ROS-based development

Programme

1. Introduction to robotics, coordinate systems, homogeneous transformations
2. Direct kinematics of articulated robots, Denavit-Hartenberg notation, analytical and numerical inverse kinematics, velocity kinematics and manipulability, path planning, robot dynamics and control, industrial robot applications
3. Kinematics of mobile robots, path planning on maps, cameras and vision, Kalman filter, simultaneous localization and mapping, industrial applications of mobile robots

Prerequisites

In order to successfully attend this course, the students must have:

- Basic knowledge in linear algebra (matrices) and analysis (derivatives)
- Basic programming skills (basic Python or similar)

Learning outcomes

After attending this course, the student will:

- Understand the operation of all types of industrial robots
- Be able to use and program industrial robots using teach pendants, programming languages, and open-source interfaces (ROS)
- Be able to design and implement integration of industrial robots with other systems based on understanding robotic controllers
- Be able to design and implement custom robotic building blocks and systems

Assessment

1. Written examination on theoretical content (50%)
2. Written examination on practical content (40%)
3. Report on laboratory work with industrial robots (10%)

Literature

Peter Corke: *Robotics, Vision and Control*, Springer-Verlag Berlin Heidelberg, 2011
Tadej Bajd, Matjaž Mihelj, Marko Munih: *Introduction to Robotics*, Springer Dordrecht Heidelberg New York London, 2013
Gregor Klančar, Andrej Zdešar, Sašo Blažič, Igor Škrjanc: *Wheeled Mobile Robotics*, Butterworth-Heinemann, 2017
Morgan Quigley, Brian Gerkey, William D. Smart: *Programming Robots with ROS*, O'Reilly Media, 2015

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Advanced Sensory Systems and Networks — 5 ECTS

Lecturer: **P. Podržaj**

Lectures: 30h | Tutorials: 4h | Labs: 26h | Project: 0h | | Lang. :

Objectives

The objectives of this course are:
- Develop the capability of designing of advanced sensory systems and networks.
- Develop the capability to transfer the theoretical knowledge to real systems.
- Develop the capability to use various software packages and programming languages related to advanced sensory systems and networks.

Programme

1. The basics of digital image processing
2. Point processing
3. Neighbourhood processing
4. Advanced algorithms
5. Machine vision
6. Application of Python for machine vision
7. Nonconventional sensors
8. Fuzzy logic
9. Neural networks
10. Sensor fusion
11. Internet
12. Web programming
13. Servers
14. Security
15. Programming of IoT applications

Prerequisites

In order to successfully achieve this course, the students are expected to:
- Have basic experience with programming in at least one programming language.

Learning outcomes

After attending this course, the student will obtain the following knowledge/skills:
- Deeper theoretical, methodological and analytical knowledge of advanced sensory system and networks.
- Mastering very demanding and complex mathematical procedures for advanced sensory systems and networks.
- Ability of unique innovations in the field of advanced sensory systems and networks

Assessment

Project

Literature

1. Thomas B. Moeslund: Introduction to Video and Image Processing, Springer, 2012
2. Ali Zilouchian: Intelligent Control Systems Using Soft Computing Methodologies, CRC Press, 2001
3. Deep Medhi: Network Routing: Algorithms, Protocols, and Architectures, Morgan Kaufmann, 2018

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Manufacturing Automation 5 ECTS

Lecturer: **D. Bračun**

Lectures: 30h | Tutorials: 8h | Labs: 22h | Project: 0h | | Lang. :

Objectives

The objectives of this course are to be understood:

- The use of automation to improve productivity and quality in production.
- The integration of basic mechatronic components in automated systems.
- The synthesis of measuring and mechatronic systems in automated inspection devices.
- The basic methods of localization and product identification.
- The use of machine vision in automation and inspection.
- The definition of performance and security of automated systems.

Programme

1. Introduction, automation types and approaches
2. PLC controllers, system integration
3. Numerically controlled and robotic systems
4. Automated inspection devices
5. Machine vision
6. Localization
7. Scada systems, automatic identification and data acquisition
8. Performance of automation systems

Prerequisites

To attend this course, the students are expected to:

- Understand basic concepts in mechanics, machine elements, mechatronics, and simple programming.

Learning outcomes

After attending this course, the student will obtain the following knowledge/skills:

- How to use automation to improve efficiency and reduce variability in production.
- Synthesis of basic building blocks of automation, localization, identification, automated inspection, use of machine vision and safety in automated systems. With the acquired competences, students can develop basic automated systems.
- Development of specifications, programming and testing of automated systems.
- Design, implementation and calibration of automated inspection devices and their integration into industrial information systems.
- Use of machine vision for automation and product inspection purposes.

Assessment

50% Theoretical exam, 30% Laboratory work, 20% Project seminar

Literature

1. Springer Handbook of Automation; Shimon Y. Nof, Springer, Berlin, Heidelberg 2009
2. Robotics, Vision and Control; Peter Corke, Springer, Berlin, Heidelberg 2011
3. Automation, Production systems, and Computer-Integrated manufacturing, Mikell P. Groover, Pearson Prentice Hall, 2008
4. Image Processing with Python, I.A. Ansari, IOP Publishing, 2024
5. Custom learning materials prepared by the lecturers.

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Photonics and Laser Sources 5 ECTS

Lecturer: **R. Petkovšek, V. Agrež**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 0h | | Lang. :

Objectives

Lasers have become essential tools across modern engineering, from precision manufacturing and micro-processing to high-speed imaging and remote sensing. This course provides engineers with a practical foundation in laser technology, focusing on how to select the right laser for an application, how different laser systems work and how lasers are used to solve real engineering problems.
This course will cover:

- How to select lasers for specific applications based on wavelength, power, and mode of operation (pulse duration, continuous mode)
- The operating principles of different laser types and their key characteristics
- Ultrashort pulsed lasers and their interaction with matter
- Laser applications in micro-processing, illumination for imaging, and sensing

Programme

1. Introduction: Why lasers matter in modern engineering
2. Fundamentals of laser light: coherence, spectra, beam shape
3. How lasers work: gain media, optical cavities, and amplification
4. Laser types: solid-state, gas, semiconductor, and fiber lasers
5. Laser-matter interaction and material processing
6. Applications: illumination for imaging, micro-machining, and remote sensing
7. Laboratory tutorials: laser operation and application demonstrations

Prerequisites

In order to successfully achieve this course, the students must have:

- Basic mechanical engineering background
- Knowledge in experimental work

Learning outcomes

After attending this course, the student will:

- Be able to explain how different laser types operate and identify their key parameters
- Be able to select an appropriate laser source for a given engineering application
- Understand how laser parameters affect material processing and imaging performance
- Be able to design basic experimental setups using lasers
- Be equipped to evaluate technical literature and continue learning independently in photonics

Assessment

50% Theoretical exam, 50% Laboratory work

Literature

"Lasers : basics, advances and applications" - Springer, 2018 - H.J. Eichler, J. Eichler, O. Lux
"Photonics: Concepts, Technology and Applications" - Blackwell's, 2019 - J. Landers
"Photonics, A Short course"- Springer, 2016 - V. Degiorgio, I. Christiani
"Fundamentals of photonics" - John Wiley and sons, Inc., 2019 - B. E. A. Saleh in M. C. Teich
"Applications of the Laser" - CRC Press, 2018 - L. Goldman

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Additive Technology — 5 ECTS

Lecturer: **E. Govekar, D. Klobčar**

Lectures: 30h | Tutorials: 14h | Labs: 16h | Project: 0h | Lang. :

Objectives

Additive manufacturing (AM) is transforming manufacturing by enabling the fabrication of highly complex, customized components and shorter development cycles. To fully leverage these benefits, engineers must understand both AM processes and the complete digital-to-physical workflow. Metal AM, in particular, presents unique process, material, and quality challenges that directly affect part performance and cost. This course provides process physics and engineering foundations of metal AM needed to evaluate AM technologies, select appropriate processes, and support industrial implementation. The objectives of the course are to:

1. Introduce the capabilities and potential of metal AM
2. Explain the full AM production chain, from design and simulation to the final product.
3. Present the systems and processes used in metal additive manufacturing
4. Enable evaluation of cost-effective technologies and business opportunities for successful implementation

Programme

(1) Introduction to additive manufacturing technologies (AM), **(2)** Basic physical principles of AM of metals, **(3)** Properties of materials for AM and incoming material quality control, **(4)** Physical basics of high density energy sources and defects in AM, **(5)** Product design specifics for AM, **(6)** Post-processing and final quality control, **(7)** DED-Arc system, process and characteristics, **(8)** DED -Arc path generation, process control and applications, **(9)** Basics of laser light metal interactions, **(10)** Metal droplet-based AM, **(11)** DED-LB/M wire systems, process and AM applications, **(12)** DED-LB/M powder systems, process and AM applications, **(13)** PBF-LB/M systems, process and AM applications, **(14)** Software for AM, **(15)** Laser based AM of multi and functionally graded materials

Prerequisites

In order to successfully achieve this course, the students must have basic knowledge on:

- Physics (high density energy source, heat transfer, phase changes)
- Materials (properties of metals)
- Manufacturing technologies 1 and 2 (metal material removal and joining processes, characteristics of cutting and joining processes)

Learning outcomes

After attending this course, the student will be able to:

- Explain the principles, potential and limitations of additive manufacturing technologies
- Understand the complete AM production chain from digital design and simulation to final part realization
- Understand metal additive manufacturing systems, processes, and key quality considerations
- Evaluate AM process selection and cost-effectiveness for industrial

Assessment

Short quiz after each lecture and two midterms (at the mid and end of the course).

Literature

1. E. Govekar, A Jeromen Lecture Notes: Laser Based Additive Manufacturing Processes "
2 D. Klobčar, U. Trdan: Lecture notes for Additive technologies.
3. U. Trdan, D. Klobčar: Tutorial notes for Additive technologies.
4.Linkan Bian, Nima Shamsaei, and John M. Usher: Laser-Based Additive Manufacturing of Metal Parts: Modeling, Optimization, and Control of Mechanical Properties, 2018
5. O. Diegel, A. Nordin, D. Motte: A Practical Guide to Design for Additive Manufacturing, Springler series in Advanced Manufacturing, 2020

CAM systems 5 ECTS

Lecturer: **F. Pušavec, P. Krajnik**

Lectures: 30h | Tutorials: 0h | Labs: 30 | Project: 0h | | Lang. :

Objectives

The objectives of this course are to provide in-depth knowledge of CAM technologies as an upgrade of machining processes. Students will become familiar with advanced CAM principles and their application to various cutting technologies, including turning, milling, 5-axis machining, and robotic machining. The course covers also machine tools, their construction, characterisation techniques, key components, tool load estimation, and basic machine tool control.

Programme

1. Introduction to CAD/CAM and CAM systems
2. Machine tool loads and cutting forces
3. CAD–CAM workflow and post-processors
4. Manufacturing systems and machine tool kinematics
5. Machine tool structure and dynamics
6. Key elements of machine tools
7. Control of machining processes
8. Planning of cutting paths and machining strategies
9. CAM for turning, milling, 5-axis machining, and robotic machining
10. Diagnostics and smart systems

Prerequisites

In order to successfully achieve this course, the students must have:

- BSc in Mechanical Engineering
- Basics on production engineering
- Good knowledge of machining processes

Learning outcomes

After attending this course, the student will:

- In-depth theoretical, methodological and analytical knowledge on the principles of computer-aided machining pathways / strategies, which is the basis for research and application work.
- Be aware of advanced CAM principles to complex machining processes
- Be able to design machining strategies and cutting paths
- Use CAM tools for virtual simulation and process optimization
- Understand machine tool components, kinematics and control fundamentals
- Be aware of diagnostic equipment and smart systems

Assessment

Assessment will be composed of three segments:

- Theoretical exam: 50%
- Lab. works: 30%
- Individual work/seminar: 20%

Literature

1. Z. Bi in X. Wang, Computer aided design and manufacturing. Hoboken, NJ; [New York, New York]: John Wiley & Sons, Inc.; ASME Press, 2020, str. XXI, 18 f., 617. ISBN 978-1-119-53421-1, [COBISS.SI-ID 44464899].
2. Handbook of manufacturing industries in the world economy. Cheltenham: Edward Elgar Publishing, 2015, str. XVII, 519. ISBN 978-1-78100-392-3, [COBISS.SI-ID 15869979].
3. J. Novak Marcinčin, I. Kuric, T. Mikac, in B. Barišić, Computer support for improvement of engineering and manufacturing activities. Košice: Faculty of Manufacturing Technologies, 2009, str. 241. ISBN 978-953-6326-63-1, [COBISS.SI-ID 14028059].
4. F. Pušavec and P. Krajnik:, Teaching materials for CAM course (slides and additional materials used in lectures and practical classes), are given to students prior start of the lecture sequence.

Smart Factories 5 ECTS

Lecturer: **N. Herakovič, M. Šimic, M. Pipan**

Lectures: 30h | Tutorials: 6h | Labs: 24h | Project: 0h | | Lang. :

Objectives

The students will gain, basics and essence of smart factories and Industry 4.0 (I 4.0) and the concept of distributed systems and development of digital twins of processes in smart factories. The main objectives are the following: 1) To gain basic concepts and approaches to design of smart factories and to learn about key technologies of I 4.0 and the concept of distributed systems; 2) To gain the basics of development of digital twins of processes in a smart factory based on the modelling of discrete and partially continuous events and to learn the basics of control of smart factories with the help of digital twins and digital agents; 3) Ability to estimate the level of digitalization of existing factories and understanding the concepts and approaches to designing smart factories or for transforming existing factories towards a smart factory; 4) Understanding the key technologies of I 4.0 and their role and usefulness in a smart factory; 5) Understanding and creation of digital twins of processes in a smart factory based on discrete and partially continuous events and to use digital twins and digital agents for control of a smart factory.

Programme

The programme is focused on smart factories and their definitions, concepts and development approaches; disciplines, systems and technologies related to Industry 4.0; referential architectural models of smart factories and concept of distributed systems; top-down and bottom-up approach when implementing solutions of I 4.0; the concept of digital twins (DT) of manufacturing processes of a smart factory; five-dimensional modelling of a DT and its key technologies; control of a smart production with a digital twin; advanced production systems integration into a smart factory.

Prerequisites

Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - The condition for admission to exam is a passing grade for exercises and other individual assignments.

Learning outcomes

After attending this course, the student knows and understands the content and mission of a smart factory compared to traditional factories; acquired knowledge is used by the student to draft and design processes in smart factories and to integrate them into the whole concept of a smart factory, to make effective use of I 4.0 technologies in a smart factory, and to produce digital twins of processes and the entire smart factory, as well as to control the whole system; to learn about key technologies of I 4.0 and the concept of distributed systems; knows and understands how to use of tools to evaluate the status of digitization of a traditional factory and computer-aided tools for drafting an efficient smart factory for various purposes and recognize of the usefulness of I 4.0 technologies in a smart factory and knows and understands how to use simulation tools for building a digital twin of a smart factory with different subprocesses.

Assessment

Contribution to the final grade:

- 50% theoretical contents (lectures, team work): Colloquium, team work presentation/defence, writing and/or oral exam
- 50% individual work in exercises, individual laboratory work (including reports).

Literature

Tao, F., Zhang, M., Nee, A.Y.C.: Digital Twin Driven Smart Manufacturing, Elsevier, 2019 / Barrenechea, M., J., Jenkins, T.: Digital Manufacturing, Open Text Corporation, 2018 / Schwab, K.: Četrta industrijska revolucija, World Economic Forum, 2016 (Slovene) / Heynitz, H. et. al.: The factory of the future, Part 1, KPMG, 2016 / Moon, I. et. al.: Advances in Production Management Systems – Smart Manufacturing for Industry 4.0, APMS 2018, Proceeedings, Part II, Seoul, Korea, 2018 / Burke, R., et. al.: The smart factory – Responsive, adaptive, connected manufacturing, Deloitte University Press, 2017 / Regber, H., Christian, M.: Introduction to Industry 4.0 – core elements and business opportunities, Festo Didactic SE, Germany, 2017.

Advanced Forming Processes 5 ECTS

Lecturer: **T. Pepelnjak, J. Valentinčič**

Lectures: 30h | Tutorials: 0h | Labs: 30h | Project: 65h | | Lang. :

Objectives

The objectives of this course are to make students aware of the new trends in forming technologies and their future challenges in the context of Industry 4.0. To be competitive in a global industrial environment, modelling the entire production chain and creating digital twins of forming processes is a crucial step. Competitive forming technologies require smart tooling concepts with implemented sensors and actuators to adapt the process to the disturbances that occur during its course.
This course will address:

- The ability to manufacture products using advanced forming processes and select the appropriate technological process.
- In-depth knowledge of standard and innovative processes for forming metallic and non-metallic materials and the optimization of their influencing parameters
- Building on the knowledge of existing forming processes, design of forming processes and their key technological parameters.
- The ability to set-up an adaptive forming process whose control is based on the developed digital twin. The forming process is performed by smart tools with integrated sensors and actuators.

Programme

1. Introduction to the context of forming technologies for metals and non-metals
2. Flexible metal forming technologies (incremental forming, flexible bending, flow forming)
3. Introduction of digital twin in forming processes
4. Smart forming tools (concepts, adaptive forming of sheet metals, adaptive forming of polymers)
5. Flexible forming systems (smart forming tool, modern forming machine, flexible auxiliary equipment)

Prerequisites

In order to successfully achieve this course, the students must have:

- Good knowledge in materials science of metals and non-metals
- Good knowledge in mechanics of materials (elastic-plastic behaviour)
- Basic knowledge in material forming
- Basic knowledge of the concept of digital twins

Learning outcomes

After attending this course, the student will:

- Be aware of the benefits and requirements of various forming processes
- Be able to select product-oriented forming technology
- Be aware of the benefits of modern flexible forming technologies
- Be able to create a simple digital model of the forming process
- Be able to create a digital twin of a simple forming process

Assessment

Oral presentation in groups with self-assessment by the classmates
The topic will be related to one of the key aspects from the course and based on a research paper in the literature

Literature

X. Guo, "Flexible Metal Forming Technologies, Principles, Process and Equipment" - Springer 2022

Lee, H., Park, N., Kim, M. et al. Recent Developments and Trends in Flexible Forming Technology. Int.J Automot. Technol. 23, 741–763 (2022). https://doi.org/10.1007

Hoppe, F., Pihan, C., Groche, P. Closed-loop control of eccentric presses based on inverse kinematic models, Procedia Manufacturing, 29, 240-247 (2019). https://doi.org/10.1016/j.promfg.2019.02.132.

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Heat Treatment — 5 ECTS

Lecturer: **R. Šturm, S. Žagar**

Lectures: 30h | Tutorials: 6h | Labs: 24h | Project: 0h | Lang. :

Objectives

The objective of the Heat treatment course is to provide the students with the necessary fundamentals for understanding the material properties given by the available heat treatment processes. A special presentation is delivered of phenomena occurring in the materials and influencing the achieved properties of core and surface of treated material.
Thus, the objectives of this course are the following:

- To find out the effect of different types of heat treatment of metallic materials, what happens from the microstructural point of view during the heating of the material and what properties of the material can be achieved with different degrees of cooling intensity and technological parameter of heat treatments.
- To know the machines and devices in connection with determining the time for the implementation of the individual elements of the process of heat treatment of the material.
- Ability to evaluate the properties of heat-treated materials in terms of the resulting microstructure and achieved properties and to achieve desired properties.
- Mastering the determination of heat treatment time for different types of heat treatments and for different product materials.

Programme

Analysis of microstructural transformations, Continuous and isothermal cooling diagram, Cooling rate and steel microstructure, Hardenability and thru-hardenability, Hardening stresses and cracks, Distortion and hardening cracks due to transformation and thermal stresses, change of microstructure and residual stresses during hardening and tempering, Local and case hardening, Thermo-chemical surface treatments, carbonization, nitriding, Plastic forming in hot and cold state, recrystallization, Heat treatment processes, annealing, Selection of tempering technological parameters, Furnace atmosphere, furnace selection, Vacuum heat treatment, Special techniques for heat treatment of steels.

Prerequisites

In order to successfully achieve this course, the students must have:

- Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.
- Basic knowledge of fundamentals in the field of material science in Materials (properties of metals, i.e. microstructural and mechanical properties and characterization).

Learning outcomes

After attending this course, the student will obtain:

- The ability to assess the behaviour of materials from the viewpoint of the selected heat treatment.
- A good knowing of surface integrity yielded by different heat treatment processes.
- The ability to evaluate the microstructural transformations in the material after different thermal and thermochemical treatments and to select an optimal heat treatment or surface hardening.
- The knowledge about the materials used in mechanical engineering, the physical properties and the microstructural phenomena characteristic to the individual material groups, with respect to the different heat treatment processes.

Assessment

Contribution to the final grade:

- 50% theoretical written exam with the mutual exam.
- 50% laboratory work (including reports).

Literature

D. R. Askeland: The science and engineering of materials, Sixth Edition, Chapman & Hall , 2011.
M. Philip, B. Bolton: Technology of engineering materials, Butterworth Heinemann, Oxford, 2007.
P.H. Morton: Surface engineering and heat treatment, The institute of metals, 1991.
Moderno proizvodno inženirstvo, priročnik, ur. Karl Kuzman, Grafis trade, 2010.
H.E. Boyer: Practical heat treatment,American society for metals, 1984.

Quality Engineering 5 ECTS

Lecturer: **D. Kramar, T. Berlec**

Lectures: 30h | Tutorials: 15h | Labs: 10h | Project: 5h | | Lang. :

Objectives

The objectives of this course are to make students aware of the importance of quality in today's world of waste and challenges in the use of raw materials. The future may be uncertain, but good quality management will enable organisations to adapt to the changing demands of a sustainable and people-friendly society.
This course will thus browse:

- The introduction to quality engineering with theoretical background and practical knowledge
- The overview of the tools and techniques of quality control and assurance and other elements of the quality management system.
- The methods of design of experiments and their application in empirical modelling and process optimization
- The application of tools and techniques of quality assurance/control in all stages of the product quality development, process planning and control

Programme

1. Introduction to Quality engineering
2. Quality Tools (7QC) and Statistical Process Control (SPC)
3. Problem solving techniques (8D, A3, 5W)
4. measurements in industry and Measurement System Analysis (MSA)
5. Risk management and Failure Mode and Effects Analysis (FMEA)
6. Product quality development, process planning and control (APQP)
7. Design of Experiments (DoE)
8. Quality management systems (Lean production, ISO, IATF)

Prerequisites

In order to successfully achieve this course, the students must have:

- Good knowledge in measurements in mechanical engineering
- Good knowledge in technical drawing and 3D modelling
  Basic knowledge in data processing and evaluation

Learning outcomes

After attending this course, the student will:

- become familiar with the quality tools and techniques of statistical process control,
- become aware of the importance of measurement techniques and acquire the ability to select appropriate measurement systems in the manufacturing process,
- learn the methods of design of experiments and their application in empirical modelling and process optimization,
- acquire the competence to apply quality tools and techniques of quality assurance/control in all stages of the product quality development, process planning and control.

Assessment

Contribution to the final grade:

- 50% theoretical written exam (lectures).
- 30% laboratory work (including reports).
- 20% seminar work as home assignment.

Literature

T. Pyzdek, P. A. Keller: Quality engineering handbook. Marcel Dekker, Inc., New York, 2003.

R. Basu: Implementing Quality – A Practical Guide to Tools and Techniques, Thomson Learning, London, 2004

J. Antony: Design of Experiments for Engineers and Scientists; Elsevier 2014

Energy Conversion Systems 5 ECTS

Lecturer: **M. Sekavčnik, M. Mori**

Lectures: 30h | Tutorials: 12h | Labs: 18h | Project: 0h | Lang. :

Objectives

- Use and integration of basic and applied energy knowledge to model energy and mass flows in complex energy systems.
- Implementation of methods for thermodynamic analysis and optimization of thermodynamic cycles to determine irreversibilities within the energy conversion chain.
- Use and development of new knowledge to design appropriate/sustainable technological solutions and concepts for modern power and heat supply.
- Evaluation of broader aspects of energy supply transformation.

Programme

The scope of the course »Energy Conversion Systems« is to provide a broad knowledge in energy supply (electricity and heat) for modern society from a) socio-economic (understanding the big picture) and b) technological (structure of primary energy sources, grid balancing, technologies available) aspects. From the understanding of the big picture of energy supply of society, which has been transformed in the direction of sustainable solutions (RES, circular economy, sectoral coupling, digitalization), individual lectures address relevant topics (theoretical and practical) so that students can critically evaluate various technological solutions in terms of a) environmental indicators, b) energy efficiency and c) basic economic feasibility. In addition to the large-scale discussion, the content covers: theoretical concepts of thermodynamic cycles their thermodynamic optimization and applications, classical thermal power plants (steam, gas, combined, ORC, CHP…), hydroelectric power plants, integration of distributed energy sources (PV- and wind power plants) into the electricity grids, hydrogen technologies, P2X, energy storage concepts, power balancing, smart grids and virtual power plants.

Prerequisites

Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

After attending this course, the student will:

- Have thorough theoretical, methodological and analytical knowledge with elements of a research work that form a basis for very demanding professional work
- Master very demanding and complex work processes and methodological tools in specialised professional fields.
- Be able of planning and managing of the working process based on creative solving of problems that are linked to the teaching and training content.
- Be able of unique innovations and critical reflections.

Assessment

- Theoretical contents (lectures) – 50 %
- Coursework – 10 %
- Laboratory exercises – 20 %

Literature

- Strauß K.: Kraftwerkstechnik, zur Nutzung fossiler, nuklearer und regenerativer Energiequellen, Springer, 2009
- Kopanos G.M., Liu P., Georgiadis M.C.: Advances in Energy Systems Engineering, Springer, 2017

Noise, Vibrations and Acoustic Engineering 5 ECTS

Lecturer: **J. Prezelj**

Lectures: 30h | Tutorials: 4h | Labs: 26h | Project: 0h | | Lang. :

Objectives

The objective of this course is to provide students with a clear, intuitive, and application-oriented understanding of sound and vibrations, from their physical origin to human perception and environmental impact. The course presents sound as a physical phenomenon that carries information and strongly influences human experience, making it relevant for students from engineering, environmental sciences, design, architecture, urban studies, and related fields.

Students will learn:

- how sound is generated by vibrations and how it propagates in air and water,
- how sound and vibrations are measured, visualized, and interpreted,
- how human perception of sound (psychoacoustics) relates to physical quantities,
- how environmental noise is assessed and managed in real environments,
- how to apply sound absorption and insulation for noise control and to influence acoustic comfort,
- how convolution and time domain analysis provide a powerful framework for understanding sound and vibration,
- how sound events can be classified, including a basic introduction to artificial intelligence methods used in acoustics.

The course emphasizes hands on experiments, demonstrations, and real world examples, enabling students to connect theory with perception and practical applications.By the end of the course, students will be able to critically interpret acoustic data, understand the relationship between measured signals and human noise experience, and recognize sound as a valuable source of information about processes, machines, and environments.

Programme

1. Introduction to sound perception and perception of different sound environments
2. Experimental methods for sound measurement and evaluation of human response
3. Digital signal processing: FFT, convolution, signal differentiation and integration
4. Time–frequency representations and transient sound analysis
5. Noise control measures using sound absorption and sound insulation
6. Introduction to artificial intelligence in acoustics: sound event classification based on feature extraction, supervised (k-NN) and unsupervised (K-Means) methods
7. Case studies from real environments and machines (urban soundscapes, machinery, transport, nature)

Prerequisites

Basic knowledge of physics and mathematics is recommended.
Students from non-engineering backgrounds are welcome; necessary physical concepts will be introduced intuitively and supported by practical demonstrations.

Learning outcomes

After completing the course, students will:

1. understand how sound is generated, propagated, and perceived,
2. be able to measure, visualize, and interpret acoustic and vibration signals,
3. understand the role of time-domain analysis and convolution in signal processing,
4. be able to assess environmental noise and acoustic comfort,
5. apply basic principles of noise control, sound absorption, and sound insulation,
6. gain introductory experience in sound event classification and data-driven analysis,
7. develop the ability to connect physical measurements with human perception and context.

Assessment

Group oral presentation with peer self-assessment
Evaluation of group performance during experimental work

Literature

Thomas D. Rossing, “Springer Handbook of Acoustics”, Springer 2007, LLC New York
David M. Howard & Jamie A.S. Angus, “Acoustics and Psychoacoustics”, Focal Press 2009, Oxford

Sustainable Electric Energy Sources 5 ECTS

Lecturer: **M. Hočevar, M. Petkovšek**

Lectures: 30h | Tutorials: 6h | Labs: 24h | Project: 0h | | Lang. :

Objectives

- To learn the principle of operation of hydro and wind power plants and solar cells.
- To learn the basic building blocks of hydropower and wind power plants.
- Understand energy conversions in machines and devices for the use of sustainable energy sources.
- Understand the interaction of machines and devices for utilizing sustainable energy sources with the grid.
- Know the ways and importance of energy storage.

Programme

- Introduction, the importance of water and wind turbines and solar cells in the electricity system today and in the future.
- Water turbines: components of the turbine flow tract and importance for operation (Pelton, Francis, Kaplan and tube turbines), properties, design and operation.
- Euler equation, velocity triangles, characteristic, efficiency and hill diagrams.
- Manufacture of water turbines (Pelton, Francis, Kaplan): blades, hub, and ring.
- Elements of a water power plant: dam, surge tank, tunnel, duct, penstock, pre-turbine valve, bypass, outlet, etc., auxiliary components of water turbine: bearings, seal, creep detector, brakes, turbine regulator, etc., spillway building blocks: barriers, locks, teeth, fish lanes.
- Wind turbines: conservation of mass flow and energy, Betz criterion, power factor, thrust coefficients, drag and lift. Wind turbine efficiency, maximum power, materials for wind turbine blades, power control, stall, velocity triangles.
- Solar cells: principle of operation, semiconductors, materials, technologies, efficiency.
- Biomass and geothermal power plants overview, operation, efficiency
- Importance of a power plant's rapid response to the provision of network system services: importance for quick start-up and primary control. Energy storage with pumped-storage power plants, batteries, etc.

Prerequisites

Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

After attending this course, the student will:

- Be capable of designing sustainable electric energy systems,
- Be able to contemplate the interaction of systems for the supply of electricity from sustainable sources and the electricity grid
- Have the ability to diagnose the specifics and failures of sustainable electric energy systems
- Be able to make decisions regarding the operation of sustainable electricity generation devices and systems
- Have ability to think critically and evaluate the environmental impact of sustainable power generation plants and systems

Assessment

- Participation in lab work – 80 % participation minimum
- Lab report – all reports must be submitted
- Laboratory exams – 50 %
- Theoretical exam – 50 %

Literature

- Kreith F., Goswami, D. Yogi, Handbook of Energy Efficiency and Renewable Energy, CRC Press, 2007.
- Raabe, J.: Hydro power: the design, use and function of hydromechanical, hydraulic and electrical equipment.- Düsseldorf: VDI, [COBISS.SI-ID 378907], 1985.

Chemical Energy Carriers 5 ECTS

Lecturer: **M. Mori, T. Seljak**

Lectures: 30h | Tutorials: 18h | Labs: 12h | Project: 0h | | Lang. : English

Objectives

- To know the basic physical and chemical properties of chemical energy carriers.
- To know the production and preparation of fossil fuels for use.
- To learn about renewable biofuels, their available potential and their interaction with food production.
- Know the procedures for extracting secondary fuels from waste materials.
- Understand the principles of energy storage, including energy conversion between transient energy forms and stored energy and including chemical, electrochemical and thermal storage principles.
- Understand the principles of designing and integrating energy storage systems into energy systems.

Programme

1. Fuel fundamentals: Physical and chemical properties of fuels, reactivity, thermal behaviour, ignition characteristics, and combustion-relevant parameters.
2. Chemical energy & thermodynamics: Energy carriers, chemical potential, reaction types, and thermodynamic principles governing fuel reactions.
3. Solid fuels & preparation: Wood, peat, coal chemistry, storage, grinding, drying, and combustion methods with emission impacts.
4. Liquid fuels & processing: Oil extraction, refining, additives, storage, fuel preparation (atomization, gasification), and combustion emissions.
5. Gaseous fuels & utilization: Natural gas reserves, transport, liquefaction, evaporation, combustion technologies, and pollutant formation.
6. Alternative, waste-derived & synthetic fuels: Biofuels (1^{st}–4^{th} generation), secondary fuels from waste, synthetic fuels, production routes, economics, and environmental effects.
7. Advanced processing, storage & system integration: Gasification, liquefaction, plastic waste recovery, thermochemical/thermal energy storage, and integration of storage in flexible energy systems.

Prerequisites

In order to successfully achieve this course, the students must meet the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

After attending this course, the student will acquire knowledge of the composition, generation and usage of chemical energy carriers - fuels and the approaches to their preparation for use. They will also acquire knowledge of renewable biofuels, synthetic fuels, waste materials and surplus energy storage from renewable energy sources, including waste conversion techniques.

Assessment

- Theory (lectures) – 40 %
- Practical coursework – 30 %
- Seminar work – 30 %

Literature

- Schorbert H., Chenistry of fossil fuels and biofuels, Cambridge University Press, 2013.
- Lecomte T. et al, Best Available Techniques (BAT) Reference Document for Large Combustion Plants.
- Industrial Emissions Directive 2010/75/EU Integrated Pollution Prevention and control, European IPPC Bureau, Evropska komisija, Bruselj, 2017.
- Barnes F. S. Large Energy Storage Sytems Handbook, CRC Press, 2011.
- Baukal C. E., Industral Burners Handbook, CRC Press, 2004.
- Rogoff M. J., Screve F., Waste-to-Energy: Technologies and Project Implementation, 3rd ed., Elsevier, 2019.

Electromobility 5 ECTS

Lecturer: **T. Katrašnik**

Lectures: 30h | Tutorials: 2h | Labs: 28h | Project: 0h | | Lang. :

Objectives

- Understanding the theoretical foundations in the field of electromobility and propulsion systems of electrified vehicle.
- Understanding the role and needs of electromobility in sector coupling paradigm.
- Understanding processes and stressors in relevant components of electrified vehicle propulsion systems.
- To know and to understand interactions in interdependencies of different components in propulsion systems of electrified vehicle.
- Understanding modelling approaches for simulating components and systems of electrified powertrains.
  Understanding development and design approaches of more efficient and environmentally friendly electrified vehicle propulsion systems for the intended use of the vehicle.

Programme

The course provides a systematic multi-scale insight in Electromobility and its role and needs within the sector coupling paradigm. In the course, we initially explain basic principles of electrified powertrains (hybrid, plug-in hybrids, battery electric, fuel cell hybrid powertrains) and position electromobility in various conversion paths of energy vectors as well as analyse corresponding energy conversion efficiencies. We continue on a lower scale with insightful engineering level explanation of electrochemistry, providing basis for profoundly studying process in batteries, fuel cells and supercapacitors. Holistic insight comprises intertwined transport, electrochemical, degradation and heat generation as well as heat transfer phenomena in batteries and fuel cells. These topics are upgraded with transfer of this knowledge to mechanistically based simulation models. The course also covers electric machines by addressing basic electromagnetics in electric machines, their classification and designs including advantages and disadvantages of different types of electric machines, thermoregulation of electric machines and basics of inverters and control of electric machines. Acquired knowledge on the component level is upscaled to provide basis for advanced performance analyses and topological, technological as well as sizing optimisation of different topologies of electrified powertrains with respect to their intended use.

Prerequisites

- Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program or equivalent.

Learning outcomes

After attending this course, the student will:

- Have in-depth theoretical, methodological and analytical knowledge with elements of research, which is the basis for scientific and professional work in the development, design and diagnostics of electrified vehicle propulsion systems.
- Independently use the acquired knowledge in the analysis, design and diagnostics of electrified vehicle propulsion systems.
- Be able to evaluate different topologies and processes in electrified vehicle propulsion systems.
- Be able to design environmentally friendly electrified vehicle propulsion systems with minimized negative environmental impact.
- Be able of independent self-driven education and research.

Assessment

1. Theory (lectures) – 50 %
2. Practical Coursework – 50 %

Literature

- Reiner Korthauer: Lithium-Ion Batteries Basics and Applications-Springer Berlin Heidelberg, 2018
- John Newman, Karen E. Thomas-Alyea: Electrochemical Systems, 3rd Edition, Wiley, 2004
- R O'hayre, SW Cha, W Colella, FB Prinz: Fuel cell fundamentals. John Wiley & Sons, 2016
- Mench, M.M. Fuel cell engines. Wiley, 2008
- Barbir, F: PEM fuel cells: theory and practice. London, Academic Press, 2013
- Guzzella L, Sciarretta A.: Vehicle Propulsion Systems - Introduction to Modeling and Optimization, 2nd ed., Springer, 2007, ISBN 978-3-540-74691-1

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Turbomachinery 5 ECTS

Lecturer: **L. Novak, M. Hočevar**

Lectures: 30h | Tutorials: 6h | Labs: 24h | Project: 0h | | Lang. :

Objectives

- To learn the principle of operation of turbine machines.
- Know the basic building blocks of turbine machines.
- Understand energy conversion in turbine machines.
- To learn how to build and operate turbine machines.

Programme

- Introduction; history and importance of turbine machinery for society
- Fundamentals of turbine machine operation; classification of turbine machines
- The first law of thermodynamics for turbine machines; characteristic curve; efficiency; losses
- Control volume approach to turbine machine analysis
- Differential approach to turbine machine analysis
- The fluid flow of turbine machines: Euler equation; velocity triangles; velocity, enthalpy and pressure conversion; blade shape; reactivity
- Radial turbine machines
- Axial turbine machines
- Theory of similarity in turbine machines
- Water turbines: types, operation, components
- Manufacture of water turbines
- The building blocks of hydropower systems

Prerequisites

Meeting the enrolment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Learning outcomes

After attending this course, the student will:

- Have in-depth theoretical, methodological and analytical knowledge with elements of research, which is the basis for very demanding scientific and professional work in the field of synthesis, design, use, and prediction of the operation of turbine machines.
- Be able to prepare complex experiments to demonstrate the characteristics and efficiency of turbine machines in power and process systems.
- Be able to apply modern methods for the design and analysis of the behaviour of turbine machines under real operating conditions.

Assessment

- Participation in lab work – 80 % participation minimum
- Lab report – all reports must be submitted
- Laboratory exams – 50 %
- Exams – 50 %

Literature

- Marko Hočevar, Introduction to turbine machinery, Faculty of Mechanical Engineering, 2019
- Eck, Bruno. Fans. 1st English ed., Pergamon Press, Oxford, 1973
- Dixon, S. L., Hall, C. A., Fluid Mechanics and thermodynamics of turbomachinery, Elsevier, 2010

Heat exchangers 5 ECTS

Lecturer: **I. Golobič, A. Kitanovski, K. Klinar, J. Kutin**

Lectures: 30h | Tutorials: 6h | Labs: 24h | Project: 0h | Lang. :

Objectives

The main objective of the subject is to provide student with knowledge in a domain of heat exchangers and their applications. With the knowledge obtained from the field of heat exchangers student will gain:

- basic knowledge for dimensioning and calculation analysis of heat exchangers;
- attain knowledge for appropriate selection and integration of heat exchanger in process and energy systems;
- attain abilities, which are needed for reduction of energy consumption in process and energy technologies, with the appropriate selection of heat exchangers;
- attain abilities, required for appropriate maintenance of systems with heat exchangers;
- attain basic knowledge on planning and design of experimental testing of heat exchangers;
- attain abilities for design of measurement systems for pressure testing, leak tightness testing, determination of pressure losses, and determination of heat exchanger efficiency.

Programme

1. Classification of heat exchangers
2. Methods for dimensioning of heat exchangers
3. Pressure drop analysis
4. Enhanced heat transfer in heat exchangers
5. Two-phase flow heat exchangers (condensers, evaporators, heat pipes)
6. Planning and managing of experimental testing of heat exchangers
7. Measurement systems and procedures in experimental testing of heat exchangers

Prerequisites

In order to achieve the objectives successfully, the students must have:

- Good knowledge in heat transfer
- Basic knowledge in metrological characteristics of measurement systems

Learning outcomes

After attending this course, the student will:

- Deep theoretical, methodological, and analytical knowledge from the field of heat exchangers and their testing, which can be transferred and supplement to other domains of process industry for high quality basic and applied research.
- Attaining of transferrable skills – which are not related only to one subject – and which enable systematic approach in analysis of the subject from the field of heat exchangers.
- Ability of unique innovations and critical reflections in the field of process and environmental engineering.

Assessment

- Theory - from lectures and exercise problems (50%)
- Individual/group work at exercises (25%)
- Practical seminary work (25%)

Literature

- S. Kakaç, H. Liu, A. Pramuanjaroenkij, Heat Exchangers: Selection, Rating, and Thermal Design, Third Edition, 2012
- Ramesh K. Shah, Dusan P. Sekulic, Fundamentals of Heat Exchanger Design, 2003
- Donatello Annaratone, Handbook for Heat Exchangers and Tube Banks design, 2010
- W. Roetzel, X. Luo, D. Chen, Design and Operation of Heat Exchangers and their Networks, Academic Press, 2019
- Tropea, C., Yarin, A.L., Foss, J.F. (ur.): Springer handbook of experimental fluid mechanics. Springer, 2007
- Baker, R. C.: Flow measurement handbook: industrial designs, operating principles, performance, and applications. Cambridge University Press, 2009

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Process Engineering 5 ECTS

Lecturer: **I. Golobič, M. Zupančič**

Lectures: 30h | Tutorials: 2h | Labs: 28h | Project: 0h | | Lang. :

Objectives

The main objective of this course is to provide (i) theoretical background and practical understanding in the field of process engineering, (ii) develop the understanding of the role of process engineering and sustainable development and (iii) strengthen the use of engineering tools for problem solving and consolidation of engineering research approach to problem solving. Most important competences gained by the students include:

- improved capability of critical, analytical and synthetical thinking for problems solving in process engineering;
- improvements of higher cognitive skills, related to the creation of new knowledge in process engineering;
- qualification to use the attained knowledge to autonomously solve technical problems and to acquire new knowledge;
- ability to find sources and critically evaluate information in the field of process engineering;
- ability to perform development, research and organisational tasks in realisation of projects in process engineering.

Programme

1. Thermal separation processes
2. Processes based on drying, absorption, adsorption and crystallization
3. Pressure-driven, membrane-based processes for liquid separation, water treatment, wastewater treatment, gas cleaning and gas separation
4. Environmental process technologies for carbon capture and storage
5. Research and development in sustainable process engineering including health, food and environmental pollution control
6. Bioprocess technologies and lyophilisation
7. Engineering and management of processes
8. Micro- and nanoscale process systems

Prerequisites

In order to achieve the objectives successfully, the students must have:

- Basic knowledge in experimental work
- Basics of thermodynamics

Learning outcomes

After attending this course, the student will be able to:

- Master demanding and complex tasks and methodological tools in process engineering.
- Plan and manage the working process on the basis of creative solving of problems that are linked to process engineering.
- Innovate and critically asses the problem solving cases in process engineering.

Assessment

Theory understanding based on lectures and exercise problems (60%); Individual/group work at exercises (20%); Practical seminary work (20%)

Literature

1. Seader, J.D, Henley, E.J., Roper, D.K., Separation Process Principles with Applications Using Process Simulators, 4th Edition, Wiley, 2015.
2. Green D.W., Southard, M. Z., Perry's Chemical Engineers' Handbook, 9th Edition, McGraw-Hill Education; 2018.
3. Basile, A., Comite, A., Current Trends and Future Developments on (Bio-) Membranes: Membrane Technology for Water and Wastewater Treatment - Advances and Emerging Processes. Elsevier, 2020.
4. Jawad, Z.A., Membrane Technology for CO2 Sequestration. CRC Press; 2019.
5. Lieberman, N., Understanding Process Equipment for Operators and Engineers. Elsevier; 2019.
6. Mersmann, A., Kind, M., Stichlmair, J., Thermal Separation Technology: Principles, Methods, Process Design (VDI-Buch), Springer; 2011.
7. Ullmann's Process and Process Engineering, Vol. 1, 2, 3, Wiley – VCH Verlag, Weinheim, 2004-
8. Basmadjian D., MassTransfer and Separation Processes, 2nd Edition, CRC Press, 2007.

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Solar Utility Technologies 5 ECTS

Lecturer: **C. Arkar, P. Poredoš**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 0h | | Lang. :

Objectives

The objectives of this course are to provide students with a comprehensive understanding of solar energy as a key renewable energy source, its physical principles, technological solutions, and role in the transition towards a sustainable energy system. The course introduces the fundamentals of solar radiation, radiative heat transfer, and the conversion of solar energy into heat, cooling, and electricity, with a particular focus on building-related applications. Special attention is given to the assessment, design, and performance evaluation of solar thermal and photovoltaic systems, as well as to their environmental impacts.

This course will thus browse:

the potential, prospects, and long-term role of renewable energy sources, with particular focus on solar energy;

the fundamentals of radiative heat transfer and the selective optical properties of surfaces relevant to solar applications;

the assessment of solar radiation and radiative heat exchange processes, highlighting their influence on the performance and efficiency of solar technologies;

the design and modelling of solar thermal and photovoltaic technologies, addressing building applications, innovative solutions, and emerging technology trends.

Programme

Renewable energy sources, their potential and prospects until 2050

Heat transfer by radiation and optical properties of surfaces for solar and long-wave radiation

Extraterrestrial and terrestrial solar radiation and irradiation, and evaluation of shading

Solar thermal systems – from passive and active systems in buildings, including solar cooling, to high-temperature systems

Photovoltaic technologies, systems in buildings, and modelling

Prerequisites

In order to successfully achieve this course, the students must have:

Good knowledge of thermodynamics and heat transfer

Learning outcomes

After attending this course, the student will:

demonstrate sound theoretical, methodological, and analytical knowledge in the field of radiative heat transfer and the conversion of solar radiation into heat, cooling, and electricity

dimension, design, and control the operation of solar energy systems, and solve related problems using creative thinking

apply critical thinking when evaluating solar technologies and systems, taking into account their environmental impacts

Assessment

Final grade: 50% two theoretical colloquia (lectures) during the semester; and 50% based on Moodle quizzes completed during laboratory work and tutorials.

Literature

uffie, J. A., Beckman, W. A. Solar engineering of thermal processes. 2nd Edition. John Wiley & Sons, Inc., New York, 1991

wari, G. N., Tiwari, A., Shyam. Handbook of Solar Energy: Theory, Analysis and Applications. Springer Singapore, 2016

edved, S., Domjan, S., Arkar, C. Sustainable technologies for nearly zero energy buildings: design and evaluation methods. Cham: Springer, 2019

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Air-Conditioning, Heating, Refrigeration, Ventilation

5 ECTS

Lecturer: **U. Stritih**

Lectures: 30h | Tutorials: 10h | Labs: 5h | Project: 15h | Lang. :

Objectives

The main objective of the subject is to provide student with knowledge in a domain of heating, refrigeration, ventilation and air-conditioning (HVAC) and their applications. With the knowledge obtained from the field of HVAC student will gain:
• basic knowledge and functioning of heating, refrigeration, ventilation and air conditioning devices and systems.
• ability to design heating and cooling systems and systems as well as ventilation and air-conditioning systems and systems.

Programme

1. Physiological, thermodynamic and meteorological basis.
2. Calculation of heat losses (winter transmission).
3. Building heating sources and installations, distribution and other heating equipment, Heat emission devices in buildings, room ventilation.
4. Calculation of heat gains (summer transmission).
5. Cooling units in buildings, air conditioning and elements, preparation and distribution of air, blowing air into a room of buildings, regulation of systems.

Prerequisites

In order to achieve the objectives successfully, the students must have:
- Good knowledge in thermodynamics and heat & mass transfer.

Learning outcomes

After attending this course, the student will have:
- Advanced theoretical, methodological and analytical knowledge in the fields of heating, cooling, ventilation and air conditioning.
- Diagnosis and problem solving in the fields of heating, cooling, ventilation and air conditioning.

Assessment

Theory: from lectures and exercise problems (50%); Project work on HVAC (50%)

Literature

1. Shan K Wang: Handbook of Air conditioning and refrigeration, McGraw-Hill, 2001
2. J. Kreider, P. Curtis, A. Rabl: Heating and cooling of Buildings, 2017
3. ASHRAE Pocket Guide for heating, refrigeration, ventilation, air-conditioning, 2017
4. ASHRAE Handbook — Refrigeration, 2022
5. ASHRAE Handbook — HVAC Applications, 2023
6. ASHRAE Handbook — HVAC System and Equipment, 2024
7. ASHRAE Handbook — Fundamentals, 2025

Computational Fluid Dynamics 5 ECTS

Lecturer: **B. Šarler**

Lectures: 30 h | Tutorials: 6 h | Labs: 16 h | Project: 8 h | | Lang. :

Objectives

To acquaint students with the basic principles of computer programs for fluid flow simulation (liquids and gases), accompanied by various other phenomena (heat transfer, species transfer, solid mechanics, electromagnetic field), based on appropriate partial differential equations (PDEs).
Teach students the in-depth use of at least one computational fluid dynamics (CFD) simulation system through practical hands-on training in a well-equipped CFD lab.
To inspire students for CFD and encourage them to study the presented fundamentals in more detail.

Programme

1. Overview of the governing equations describing different types of fluid flow.
2. Essential elements and historical developments of CFD.
3. Space and time discretisation of transport phenomena fields.
4. Elaboration of the finite volume method for CFD.
5. Industrial CFD examples from the fields of materials processing, aerodynamics, biomedicine, environmental sciences etc.

Prerequisites

To achieve the objectives successfully, the students have to possess:

- Knowledge of the basics of thermofluid sciences (thermodynamics, heat transfer and fluid flow).
- Knowledge of the fundamentals of numerical methods.

Learning outcomes

After attending this course, the student will:

- Understand the basic principles and structure of CFD simulation systems.
- Understand discretisation problems: consistency, stability, convergence, discretisation order, numerical diffusion etc.
- To be aware of the peculiarities when solving the fluid flow equations and the problems regarding numerical modelling of turbulent flow.
- To be able to choose the appropriate formulation and numerical approach for the given physical problem and to assess the correctness of the obtained results.
- To be equipped with the practical skill of solving a spectrum of problems by a CFD simulation system.

Assessment

Theory - from lectures and exercise problems (50 %); Individual/group work at exercises (25 %); Project with a CFD code (ANSYS FLUENT and/or OpenFOAM) (25 %)

Literature

1. F. Moukalled, L. Mangani, M. Darwish, The Finite Volume Method in Computational Fluid Dynamics: An Advanced Introduction with OpenFOAM and Matlab, Springer Verlag, Cham, 2016.
2. H. K. Versteeg, W. Malalasekera, An Introduction to Computational Fluid Dynamics, The Finite Volume Method, 2nd Edition, Pearson, Harlow, 2007.
3. G.R. Liu, Mesh Free Methods: Moving Beyond Finite Element Method, CRC Press, Boca Raton, 2nd Edition, 2009.

UNIVERSITY OF LJUBLJANA
Faculty of Mechanical Engineering

Refrigeration and Heat Pumps — 5 ECTS

Lecturer: **A. Kitanovski, K. Klinar**

Lectures: 30h | Tutorials: 10h | Labs: 20h | Project: 0h | Lang. : English

Objectives

The main objective of the subject is to provide student with knowledge in a domain of refrigeration and heat-pumping:

- to obtain knowledge in management of processes for: Food refrigeration and freezing; Cooling in buildings; Industrial refrigeration; Commercial refrigeration; Refrigerated transport; Cooling in electronics; Low temperature refrigeration – Cryogenics; Special refrigeration applications;
- to obtain basic and applied knowledge for development of refrigeration processes in different refrigeration devices and systems;
- to obtain basic and applied knowledge for development of heat pumps and related systems;
- to gain capabilities of critical thinking, analysis and design of refrigeration devices and heat pumps;
- to establish knowledge on newest and emerging refrigeration and heat pump technologies or knowhow, and their implementation in different engineering domains.

Programme

1. Thermodynamics of basic refrigeration cycles
2. Vapor-compression refrigeration and heat pumping
3. Sorption refrigeration and heat pumping
4. Enhanced heat transfer in heat exchangers
5. Gas refrigeration cycle
6. Solid-state refrigeration
7. Applications

Prerequisites

In order to successfully achieve this course, the students must have:

- good knowledge in heat and mass transfer.

Learning outcomes

After attending this course, the student will have:

- deep theoretical, methodological and analytical thinking with research capabilities, which is the basis for understanding and implementation of solutions in the field of different refrigeration and heat pump technologies;
- knowledge of design of complex processes and systems from the field of refrigeration and heat pumping. Obtained skill will allow to solve analytical and numerical problems in the field of refrigeration and heat pumps;
- capability for research and development and implementation of original findings/creations from the field of refrigeration or heat pump applications, which person can implement.

Assessment

Theory - from lectures and exercise problems (50%); Work and collaboration in laboratory and auditorial problems (20%); Practical seminar or group project (30%)

Literature

1. G. F. Hundy et. al: Refrigeration and Airconditioning, Elsevier, 2008
2. Roy J. Dossat, Thomas J. Horan, Principles of Refrigeration, 2001
3. R. Radermacher, Y. Hwang, Vapor Compression Heat Pumps with Refrigerant Mixtures, CRC Press, 2005
4. Poredoš A. et al: Heat pumps for heating and cooling, University of Ljubljana, 2018