RUHR – UNIVERSITÄT BOCHUM
FACULTY OF MECHANICAL ENGINEERING

Master's Programme Mechanical Engineering

Specialisation Sustainable Energy Systems & Circular Process Engineering

Module Catalogue

Valid from summer semester 2023

In addition to the course schedules the module catalogue includes summaries of the contents of the modules. Only the module catalogue published on the website of the Faculty of Mechanical Engineering at the Ruhr-Universität Bochum is valid. Older module catalogues are to be found in the archive. Regular revisions of the module catalogue are to be expected which is why the module description valid in the semester of the last lecture is always decisive for the module examination.

24 April 2023

Value of the module grade for the final grade

Percentage of the final grade [%] = „CP of module" * 100 * FAK / DIV

FAK = 1,0 for the modules of all study sections

DIV = 90

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Thermodynamics of Mixtures (5 ECTS,).. 52

Turbulence Modelling (5 ECTS,).. 54

2) STEM Modules M.Sc. Mechanical Engineering, ECTS: 15

Here you will only find the STEM modules offered by the Faculty of Mechanical Engineering. Module descriptions of other possible modules can be found in the corresponding areas/faculties.

Advanced Topis of Experimental Micromechanics and Microtribology (5 ECTS, each winter semester).. 6

Computational Fracture Mechanics (5 ECTS, each winter semester)... 11

Dynamic Structures and Active Control (5 ECTS, each summer semester)... 17

Fundamental Aspects of Materials Science and Microengineering (5 ECTS, each summer semester).. 25

Introduction to Three-dimensional Materials Characterization Techniques (5 ECTS, jedes Wintersemester)... 34

Materials for Aerospace Applications (5 ECTS, each winter semester)..38

Multiscale Mechanics of Materials (5 ECTS, each winter semester)... 40

Service Engineering (5 ECTS, each summer semester)..48

Solidification Processing (5 ECTS, each winter semester)...50

3) Scientific Paper M.Sc. ME, ECTS: 30

Master's Thesis (30 ECTS, each semester).. 36

4) non-STEM Module M.Sc. Mechanical Engineering, ECTS: 5

Non-STEM modules may be elected from the range of non-STEM related master's courses of the Faculty of Mechanical Engineering or other faculties as long as the admission is allowed. The elective module should not contain STEM content and be useful for engineering education in general. The examination board decides on admissibility upon application.
Module descriptions of possible modules can be found in the corresponding areas/faculties.

Advanced Topics of Experimental Micromechanics and Microtribology

Advanced Topis of Experimental Micromechanics and Microtribology

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	9th Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Advanced Topis of Experimental Micromechanics and Microtribology	a) 4 SWS (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr. Francesca di Mare

a) Dr. St. Brinckmann

Admission requirements

Learning outcome, core skills

After successful completion of the module, the students will be able to:

- Use and evaluate different experimental techniques and design new setups based on macroscopic and microscopic mechanical testing designs
- Use interpreted programming to extract advanced characteristics of micromechanical and microtribological data
- Derive equations for micromechanics and create numerical models that mimic the experimental characteristics and limitations
- Use statistics to generate uncertainty measures for mechanical experiments at the microscale; compare the analytical models with numerical approximations

Contents

a)

This modul discusses how micromechanics and microtribology can be used to extract advanced material phenomena of metal deformation at the microscale. Among other topics, this module will discuss:

- The history of experimental micromechanics using indentation and nanoindentation
- Limitations of experimental micromechanics and microtribology
- File formats of experimental micromechanics, conversion and size limitations
- An interpreted computer languages and its use to investigate phenomena at the microscale
- Statistical uncertainty analysis based on the derivation of mechanical equations and discussion of uncertainty dependence and independence
- Numerical models that mimic experiments at the micrometer scale. Overview of continuum and fracture mechanics based models
- Design of numerical mechanical models and evaluation of their limitations. Comparison of these limitations with the statistical uncertainty of experiments
- Design of new micromechanical and microtribological experiments, evaluation of the expected stress state and possible crack formation

Educational form / Language

a) Tutorial (1 SWS) / Lecture (3 SWS) / English

Examination mode

• oral online exam, depending on the number of participants

Requirements for the award of credit points

passed oral exam
Module applicability no information
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information The lecture is given in the English language in live online lectures and practical work. The course is designed for an optimal learning experience of 5-10 students.

Chemical Energy Storage and Carbon-Based Feedstock

Chemical Energy Storage and Carbon-Based Feedstock

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Chemical Energy Storage and Carbon-Based Feedstocks	a) 4 SWS (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Thomas Ernst Müller

a) Dr. rer. nat. Berthold Fischer

Admission requirements

Recommended previous knowledge: Previous knowledge of chemistry is recommended

Learning outcome, core skills

Today’s energy and chemical feedstock supply and storage systems are based to a large extent on fossil resources. They need to be converted in the next decades into energy supply and feedstock systems that rely to a large extend on renewable feedstock. Most renewable sources are of intermittent nature and this will lead to completely new system design requirements to maintain reliable energy systems and a continuous feedstock supply for the chemical industry and other industries. Knowledge of these new systems and their development and implementation will be essential for graduates in the future.

Understanding that the reliability of the transformed energy systems and feedstock supply chain will rely on to a large extent on the three pillars energy storage, renewable (over)production, and carbon-based feedstocks

Ability to assess the different possibilities to deal with and balance the time-offset between power generation and power demand, know different technologies to store energy and distinguish different storage solutions and applying them to a given storage or feedstock

Understanding of the different types of carbon-based feedstocks and the application and industry where they are most suitable.

Ability to do a basic life cycle assessment of chemical feedstock supplies and chemical storage systems and their respective chances and boundary conditions for large scale adoption and implementation.

After successful completion of the module students should be able to

- have enhanced subject and method competences in the area of chemical energy storage and carbon-based feedstocks
- be familiar with current developments and technical principles in the area of chemical energy storage and carbon-based feedstocks
- compare different chemical energy storage concepts and carbon-based feedstocks and assess the suitability of these concepts in a process-chain analysis and under consideration of process technology aspects and applications
- assess and discuss thermodynamic and kinetic aspects of chemical energy storage and carbon-based feedstocks
- explain, estimate and calculate potentials, energy densities and efficiencies of storage technologies and concepts

- be familiar with interdisciplinary thinking at the interface of engineering and chemistry and can tackle actual and future problem definitions in the chemical industry, in particular regarding sustainability and use of renewable resources such as CO2and others
- enter industrial R&D in a cutting-edge field in the area of the „Energiewende“ and “„Wasserstoffrepublik Deutschland“

Contents

a)

Since the beginning, human beings have made use of energy storage; history of energy storage from the perspective of the carbon cycle

- Thermodynamic basics of chemical energy storage
- Overview of energy storage technologies (including non-chemical)
- Technology and characteristics of conventional power plants
- Biogenic energy carriers; photosynthesis as the first energy storage process; fossil energy as a form of ancient biomass; solid (wood, coal), fluid (oils, crude oil) and gaseous (natural gas) biogenic energy carriers
- Chemical energy carriers in the energy system, power-to-gas (e.g. methane) and power-to-liquid (e.g. methanol); energy storage *via* fuels
- Electrochemical basics and applications for electrochemical energy storage; systems for electrochemical energy conversion and storage (batteries, electrolysis, fuel cells)
- Hydrogen storage technologies (generation, compression, liquefaction, adsorption, chemical binding to a carrier)
- Energy storage as heat
- Energy scenarios and modelling; Life Cycle Assessment
- What is a Feedstock? Renewable *vs*. depleting feedstock; renewable carbon-based feedstocks, CO2, biomass, biocoal; current feedstock consumption
- Value chain of fuels and chemicals; agricultural and industrial applications
- Renewable carbon-based feedstock for energy; biofuels from first generation corn-based, ethanol, biodiesel; second generation biofuels, cellulosics, oils, grasses; third and fourth generation, biofuels, algae
- Chemical conversion routes for carbon dioxide
- Biorefinery; production of aromatics from lignin; renewables as feedstock for polyesters, polycarbonates and polyurethanes

Educational form / Language

a) Tutorial (2 SWS) / Lecture (2 SWS) / English / German

Examination mode

• Written examination 'Chemical Energy Storage and Carbon-Based Feedstocks' (90 Min.ungraded, If the number of participants is less than 10, the examination may be conducted orally)

• Presentation (either in German or English) on a technical process (part of the module grade 100 %, topics and dates will be determined in the course tutorial).

Requirements for the award of credit points

- Passed final module exam: written exam
- Presentation on a technical process (topics and dates will be determined in the course)

Module applicability

M. Sc. Mechanical Engineering

M. Sc. Sales Engineering and Product Management

M. Sc. Umweltingenieurwesen

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

Lecture English and German, exercises preferably German but also English possible

Computational Fracture Mechanics

Computational Fracture Mechanics

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	9th Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Computational Fracture Mechanics	a) 4 SWS (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)
Prof. Dr. Alexander Hartmaier
a) Prof. Dr. Alexander Hartmaier

Admission requirements
Recommended previous knowledge: Basic knowledge about solid mechanics and plasticity

Learning outcome, core skills
The students attain the ability to independently simulate fracture including plasticity for a wide range of materials and geometries. Based on the acquired understanding of the different types of brittle fracture and ductile failue of materials, they are enabled to choose appropriate fracture mod-els and to implement them in a finite element environment.They gain suffiecient knowledge about the theoretical background of the diffrent types of fracture models, to study the relevant literature independently. On an engineering level, the students are able to discriminate between situations, where cracks in a structure or component can be tolerated or under which conditions cracks are not admissible,respectively.

Contents
a)
Subject aims

Phenomenology of fracture/Fracture on the atomic scale

Concepts of linear elastic fracture mechanics

Concepts of elastic-plastic fracture mechanics

R curve behavior of materials

Concepts of cohesive zones (CZ), extended finite elements (XFEM) and damagemechanics

Finite element based fracture simulations for static and dynamic cracks

Application to brittle fracture & ductile failure for different geometries and loadingsituations

Educational form / Language
a) Tutorial (2 SWS) / Lecture (2 SWS) / English / German

Examination mode
• Written exam 'Computational Fracture Mechanics' (120 Min., Part of modul grade 100 %)
• alternativ oral exam (30 Minuten) (Anteil an der Modulnote 100 %)

Requirements for the award of credit points
Passed final module examination: Written exam oder oral exam

Module applicability
MSc. Maschinenbau

MSc. Materials Science and Simulation

Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information

Computer Aided Process Design

Computer Aided Process Design

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 LP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Computer Aided Process Design	a) 4 SWS (60 h)	a) 90 h	a) jedes SoSe

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Marcus Grünewald

a) Dr.-Ing. Julia Riese

Admission requirements

Recommended previous knowledge: Recommended prerequisites: basic knowledge in Aspen Plus® or other flowsheet simulation tool in chemical engineering

Learning outcome, core skills

After successful completion of the module, students are able to

- Develop processes for the manufacture of chemical products and assess their impact on the environment and society,
- Identify the necessary information needs for these tasks, find sources of information, and obtain the relevant information,
- Implement a complex process in common flowsheet simulation environment (Aspen Plus®), perform simulations and critically evaluate their results using parameter and sensitivity analysis, and derive further need for action from the results,
- Familiarize themselves independently and systematically with new tasks in a short period of time.

Contents

a)

The course teaches simulation methods for complex processes in the chemical industry. In particular, the following topics are addressed:

- Tasks of and requirements for successfully implement and run process simulations,
- Simulation types and their advantages and disadvantages,
- Criteria for selecting models to represent common unit operations, as well as the required data basis and limitations of the models,
- Solution strategies for complex recycle loops,
- Process analysis tools such as sensitivity analysis, design specs and optimization,
- Simulation-based options for heat and resource integration,
- Analysis and preparation of simulation data for the presentation of relevant results.

Educational form / Language

a) Übung (2 SWS) / Vorlesung (2 SWS) / Englisch

Teaching methods

• Mündlich 'Computer Aided Process Design' (45 Min., Part of modul grade 100 %, Oral examination in small groups (45 minutes))

Requirements for the award of credit points

Passed final module exam: Oral examination in small groups

Module applicability

- MSc. Maschinenbau
- MSc. Sales Engineering and Product Management
- MSc. Umweltingenieurwesen

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

Demand and Supply in Energy Markets Demand and Supply in Energy Markets					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8th Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Demand and Supply in Energy Markets			**Contact hours** a) 4 SWS (60 h)	**Self-study** a) 90 h	**Frequency** a) each summer
Module coordinator and lecturer(s) Prof. Dr. rer. pol. Valentin Bertsch a) Prof. Dr. rer. pol. Valentin Bertsch					
Admission requirements Recommended previous knowledge: Recommended prior knowledge: Basic knowledge of energy economics, such as that covered in the B.Sc. module Energy Economics. Furthermore, solid prior knowledge of investment appraisal is advantageous. For participation in the exercises, a (mobile) computer with a spreadsheet program (e.g. Excel) is advantageous.					
Learning outcome, core skills After successful completion of this module the students are able to: • name different types of energy markets and explain their purpose and functionality. • name the main technological, socio-economic and political drivers of energy demand and explain how they each change energy demand over time or between energy carriers. • assess how the expansion of renewable energy sources, energy efficiency and energy systems integration across sectors and scales impact energy demand and supply within and across energy carriers. • apply the concepts learnt to complex case studies, analyse and interpret the corresponding results and draw conclusions for the transformation of the energy system. • work independently in project groups and present results of their group work in an understandable way. Moreover, the students will have • developed the ability to think in a networked and critical way and are able to select and apply established methods and procedures, • acquired in-depth and interdisciplinary methodological competence and are able to apply it in a situationally appropriate manner. The students practice scientific learning and thinking and can • develop complex problems in technical systems in a structured way and solve them in an interdisciplinary way using suitable methods, • transfer knowledge/skills to concrete systems engineering problems.					
Contents a) - Basics of economics - Fundamentals of energy markets - Energy demand: • Energy demand by sector and energy carriers at global and regional level					

- Bottom-up analysis of energy demand
- Top-down analysis of energy demand

- Energy supply:

- Investment appraisal
- Investing in supply expansion

- Group work on complex case studies focussing on how policy, regulation and markets affect energy demand (between sectors, over time) and supply

During the lecture and exercise, students work in project groups on concrete case studies, prepare a written paper and present their results at the end of the term.

Educational form / Language

a) Tutorial (1 SWS) / Lecture (3 SWS) / English

Examination mode

• Written exam 'Demand and Supply in Energy Markets' (90 Min., Part of modul grade 100 %, onsite or online)

• Course-related tasks: Group work (40 hours, deadlines will be announced at the beginning of the semester) (If the group work is completed before the final module exam, optional bonus points are possible for the exam).

Requirements for the award of credit points

- Passed written exam (Note: The grade is based on the written exam only)
- Successful completion of the group work (details will be announced at the beginning of the semester)

Module applicability

- MSc. Mechanical Engineering
- MSc. Sales Engineering and Product Management
- MSc. Umweltingenieurwesen

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

Dynamic Structures and Active Control Dynamic Structures and Active Control					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8th Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Dynamic Structures and Active Control			**Contact hours** a) 3 SWS (45 h)	**Self-study** a) 105 h	**Frequency** a) each summer
Module coordinator and lecturer(s) Prof. Dr. Tamara Nestorovic a) Prof. Dr. Tamara Nestorovic					
Admission requirements Basic knowledge of control systems is of advantage					

Learning outcome, core skills

The students acquire an overall competence in fundamental methods of active structural

control. After successfully completing the course, the students are able to recognize the problems in practice and to apply the acquired knowledge in solving engineering problems in the field active control of mechanical structures, with the focus on active vibration control. In particular, the students:

- have basic knowledge in behavior and modeling of piezoelectric materials for applications in smart structures and active systems
- have knowledge in model development of mechanical structures for the control system design (linear time invariant systems in the state-space and transfer function form)
- are able to perform the model-based system analysis in time and frequency domain
- are able to design basic control structures with compensator and feedback gain systems
- are able to independently simulate control systems (PID and pole placement controller)
- have knowledge in discrete-time control systems
- are able to use Matlab/Simulink software and toolboxes for the control system analysis, design and simulation

Contents

a)

The course presents an overall insight in the modeling and control of active structures and systems. Basic terms and definitions are introduced along with presentation of the potential application fields. For the purpose of the controller design for active structural control, the basics of the control theory are introduced: development of linear time invariant models, representation of linear differential equations systems in the state-space form, controllability, observability and stability conditions of control systems. The parallel description of the modeling methods in structural mechanics enables the students to understand the application of control approaches. For actuation/sensing purposes multifunctional active materials (piezo ceramics) are introduced as well as the basics of the numerical model development for structures with active materials. Control methods include time-continuous and discrete-time controllers in the state-space for multiple-input multiple-output systems, as well as methods of the classical control theory for single-input single output systems. Differences and analogies between continuous and discrete time control systems are specified and highlighted on the basis of a pole placement method. Closed-loop controller design for active structures is explained. Different application examples and problem solutions will show the feasibility and importance of the active structural systems development. The students also get insight into basics of

active structural health monitoring. Within this course the students learn computer aided controller design and simulation using Matlab/Simulink software. Students will implement the acquired knowledge in the framework of a seminar paper related to the controller design supported by Matlab Software.
Educational form / Language a) Lecture with tutorial / English
Examination mode • Written exam 'Dynamic Structures and Active Control' (90 Min., Part of modul grade 100 %) • Homework – Seminar paper based on the computer exercises; deadlines will be announced at the beginning of the semester
Requirements for the award of credit points • Passed final module examination and passed Seminar paper
Module applicability MSc Maschinenbau
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information Lectures with exercises, computer exercises and tutorials (3h / week) / English

Energy Systems Analysis Energy Systems Analysis					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9th Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Energy Systems Analysis			**Contact hours** a) 4 SWS (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Dr. rer. pol. Valentin Bertsch
a) Prof. Dr. rer. pol. Valentin Bertsch

Admission requirements
Recommended previous knowledge: Recommended prior knowledge: Basic knowledge of energy economics, such as that covered in the B.Sc. module Energy Economics. Furthermore, solid prior knowledge in operations research as well as investment appraisal are advantageous. Exercises are organised as computer tutorials. If possible, these take place in the CIP pool(s) on campus. If students want to work on the exercises outside the CIP pool hours, they need a (mobile) computer on which they can install an open-source energy system model, which is provided by the chair.

Learning outcome, core skills
After successful completion of this module the students are able to

- name categories of energy systems models and explain the methodological concepts behind the different categories.
- explain and apply approaches for generating energy systems model input data in a structured way.
- apply selected methods and models to practical problems (e.g. unit commitment optimisation).
- interpret results from energy systems models and draw conclusions to support decision making.
- discuss strengths and weaknesses of the methods and models used and to discuss and derive potential for improvement.

Moreover, the students will have

- developed the ability to think in a networked and critical way and are able to select and apply established methods and procedures,
- acquired in-depth and interdisciplinary methodological competence and are able to apply it in a situationally appropriate manner.

The students practice scientific learning and thinking and can

- develop complex problems in technical systems in a structured way and solve them in an interdisciplinary way using suitable methods,
- transfer knowledge/skills to concrete systems engineering problems.

Contents
a)
Modelling and Simulation of Energy Systems

- Introduction and overview of energy systems analysis
- Fundamental optimisation models for power systems analysis
    - Optimal unit commitment (short-term planning)

- Optimal capacity expansion (long-term planning)

- Scenario planning approaches
    - Introduction to scenario planning
    - Combination of scenario planning and power systems analysis
- Investment appraisal
- Selected case studies

Decision Analysis and Assessment of Strategies

- Types of decision environments and models
- Structuring decision problems
    - Generating objectives and hierarchies
    - Generating and preselecting alternatives
- Preference elicitation
- Aggregation functions and sensitivity analysis
- Selected case studies

During the exercises, students work on concrete case studies using an open source energy systems model to be installed on their (mobile) computers, and practise preparing input data, processing model results and drawing conclusions.

Educational form / Language

a) Tutorial (1 SWS) / Lecture (3 SWS) / English

Examination mode

• Written exam 'Energy Systems Analysis' (90 Min., Part of modul grade 100 %, onsite or online)

• Assignments accompanying the course: Computer tutorials / exercises (details will be announced at the beginning of the semester).

Requirements for the award of credit points

- Passed written exam (Note: The grade is based on the written exam only
- Successful completion of the computer exercises (details will be announced at the beginning of the semester)

Module applicability

- MSc. Mechanical Engineering
- MSc. Sales Engineering and Product Management
- MSc. Umweltingenieurwesen

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

<table>
<tr><td colspan="6">Specialized Laboratory Energy Technology
Specialized Laboratory Energy Technology</td></tr>
<tr><td>Module number</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Semester[s]
8th/9th Sem.</td><td>Duration
1 Semester</td><td>Group size
50</td></tr>
<tr><td colspan="3">Courses
a) Specialized Laboratory Energy Technology</td><td>Contact hours
a) 2 SWS (30 h)</td><td>Self-study
a) 120 h</td><td>Frequency
a) each Sem.</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Dr.-Ing. David Engelmann
a) Prof. Dr.-Ing. V. Scherer, Prof. Dr. Francesca di Mare, Prof. Romuald Skoda, Prof. Dr. rer. pol. Valentin Bertsch</td></tr>
<tr><td colspan="6">Admission requirements
none</td></tr>
<tr><td colspan="6">Learning outcome, core skills
After successful completion of the module, students are able to
• explain the functionality, the field of application as well as the underlying physics of the setups presented in the experiments
• analyse and proof gathered experimental data
• prepare, illustrate and present experimental results
• independently work out solutions to questions related to the particular experiments</td></tr>
<tr><td colspan="6">Contents
a)
The chairs Energy Technology (LEAT), Thermal Turbomachinery and Aero Engines (TTF), Energy Systems and Energy Economics (EE) as well as Hydraulic Fluid Machinery (HSM) offer a specialized laboratory to students of the master’s programme Mechanical Engineering in each winter and summer semester. By participating in five experiments within one semester, students are taught interesting and innovative techniques in the energy sector. The portfolio includes, among others, the following experiments, which can change from summer to winter semester:
• Determination of the calorific value of a solid fuel using a calorimeter (LEAT)
• Flow measurement using Laser Doppler Anemometry (LEAT)
• Elemental analysis (LEAT)
• Experimental determination of flow parameters of a compressor profile (TTF)
• Performance testing of a screw compressor (TTF)
• Determination of the engine characteristics of a radial compressor stage (TTF)
• Function and possible field of application of a gas engine driven combined heat and power plant (EE)
• Cavitation in centrifugal pumps (HSM)
• Numerical test rig for centrifugal pumps (HSM)
• Measurement oft pressure distribution around a NACA profile (HSM)</td></tr>
<tr><td colspan="6">Educational form / Language
a) Laboratory / English/ German</td></tr>
</table>

Examination mode • Compulsory attendance
Requirements for the award of credit points • Participation in the preliminary meeting • Participation in all 5 experiments offered within one semester • Passed pre-tests for all 5 experiments offered within one semester • Passed detailed report of the first assigned experiment • Passed presentation of the second assigned experiment
Module applicability MSc. Mechanical Engineering
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information Interested students register for the specialized laboratory in FlexNow within 6 weeks before the beginning of the semester.

Process Technology Laboratory

Process Technology Laboratory

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	8th/9th Sem.	1 Semester[s]	40

Courses	Contact hours	Self-study	Frequency
a) Fachlabor Verfahrenstechnik	a) 2 SWS (30 h)	a) 120 h	a) each Sem.

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Eckhard Weidner
a) Dr.-Ing. Stefan Pollak

Admission requirements

Recommended previous knowledge: All students with admission to the master's program in mechanical engineering are eligible to participate.

Learning outcome, core skills

Subject-specific laboratories in the Master's program generally serve to acquire the skills necessary for entry into experimental (subject-specific) scientific work. Since the relevant practical skills depend to a large extent on the chosen focus, subject-specific laboratories are offered. In the specialised Process Technology Laboratory, the focus is on basic unit operations and the acquisition and evaluation of measurement data.

After the successful completion of the module, the students

- practice scientific thinking, learning and working in a more in-depth form.
- are familiar with the comprehensive engineering fundamentals in the area of their major field of study and are able to apply these to subject-specific problems.
- have practical skills in the use of measurement setups and experimental equipment.
- present their own experimental results and are proficient in recording and processing measurement results.
- possess both disciplinary and interdisciplinary methodological competence and are able to apply these in a manner appropriate to the situation.

Contents

a)
In the specialised laboratory, students of the master's program in mechanical engineering with a specialization in energy and process engineering, learn basic operations of process engineering and the associated measurement and analysis technology.

The laboratory consists of 6 experiments, which are regularly updated and can therefore vary. Which experiments are offered depends on the availability of equipment and supervisors. The experiments are different in summer and winter semesters. Currently available experiments are:

Vapor Pressure / Particle Image Velocimetry / Orifice Flow / Bubble Column
Viscosimetry / Particle Technology / Heat Exchangers / Density Measurement
Fluidised Bed / Spray Drying / Boiling Equilibrium / Rectification

The laboratory is absolved in groups. A group ideally consists of four students. All experiments must be prepared using the script provided. At the beginning of each experiment, this preparation will be checked in an oral entrance examination. As a follow-up, each group prepares a protocol or gives a presentation for each experiment.
Educational form / Language a) Praktikum / German / English
Examination mode • Praktikum 'Process Technology Laboratory' (6 Mon., Part of modul grade 100 %, Experimental protocols or presentation of the results) • Anwesenheitspflicht - Vorbereitung, Versuchsbeteiligung und Nachbereitung
Requirements for the award of credit points Preparation, participation in the experiment and follow-up are prerequisites for receiving a grade. To pass the laboratory, all 6 experiments must be passed. The student will receive an overall grade for all 6 protocols or presentations.
Module applicability MSc. Mechanical Engineering
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information

Fundamental Aspects of Materials Science and Microengineering

Fundamental Aspects of Materials Science and Microengineering

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	8th Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Fundamental Aspects of Materials Science and Microengineering	a) 4 SWS (60 h)	a) 90 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Gunther Eggeler

a) Prof. Dr.-Ing. Gunther Eggeler, Prof. Dr. Tong Li, Prof. Dr.-Ing. Alfred Ludwig

Admission requirements

Recommended previous knowledge: keine

Learning outcome, core skills

The students will learn:

- to evaluate the thermodynamic parameters which stabilize solid solutions and which lead to the formation of ordered phases and heterogeneous particle/matrix systems.
- to appreciate the role of microstructure in determining functional and structural materials properties in four case studies.
- to use the methodology of combinatorial materials research to assess material libraries with the objective to identify new alloy compositions and to invent new materials. They will appreciate the important role of micro engineering in this respect.
- to appreciate the applied side of fields like high temperature materials (lifetime of components in high temperature service) and shape memory alloys (acceptance criteria for shape memory actuators and shape memory implants).
- that there is plenty of space for improving existing and inventing new materials, and that progress in this area is vital for progressing the field and for technological success in materials science and technology.
- to familiarize themselves with the English language, which is used in the academic and technical literature of materials science and microengineering. The lecture will also develop communication skills in English.

Contents

a)

The students will learn to apply basic materials science concepts (elements of microstructure, phase diagrams, diffusion, strength, physical properties) to four material classes, which are in the focus of todays materials research and feature fascinating structural and functional properties: high entropy alloys (HEAs), intermetallic phases (IPs), single crystal Ni-base superalloys (SX) and shape memory alloys (SMAs). These four material classes have quite different microstructures and properties, but these can be understood on the basis of the concept toolbox, which the students have learned in their basic studies.

Key materials science concepts from the fields of solid state physics (crystal structures and crystal defects), thermodynamics (thermodynamics of mixtures), kinetics (diffusion) and mechanics (uniaxial testing, fracture mechanics) will be reviewed. Emphasis is placed on the importance of the strong link between elementary atomistic, crystallographic, thermodynamic/kinetic and microstructural processes and the functional and structural properties of materials/components on the macro scale. The following subtopics will receive special attention:

- Importance of atoms and electrons in materials engineering and the transition from atoms to alloys and from alloys to components
- Thermodynamic concepts in materials engineering and fundamentals of alloy design (with a special focus on ternary phase diagrams)
- Combinatorial materials research
- Kinetic concepts in materials science and engineering (with a focus on microstructural evolution)
- Basic concepts of solid state phase transformations
- Understanding and application of knowledge to four materials classes: high entropy alloys, intermetallic phases, single crystal superalloys and shape memory alloys
- Acquisition of knowledge about high temperature strength (example: superalloys), fracture mechanics and fatigue (example: shape memory alloys), structure and properties of alloys and compounds (chemistry, crystallography and physical properties) and methods for the invention of new materials (micro engineering and combinatorial materials research)

Educational form / Language

a) Lecture with tutorial / English / German

Examination mode

• Written exam 'Fundamental Aspects of Materials Science and Microengineering' (120 Min., Part of modul grade 100 %)

Requirements for the award of credit points

Passing the exam

Module applicability

- MSc. Maschinenbau
- MSc. Sales Engineering and Product Management
- MSc. Materials Science and Simulation

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

Gasdynamics Gasdynamics					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9th Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Gasdynamik			**Contact hours** a) 4 SWS (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Romuald Skoda
a) Dr.-Ing. Maximilian Paßmann

Admission requirements
Recommended previous knowledge: Bachelor degree in Mechanical Engineering Fundamental of Fluid Mechanics (Grundlagen der Strömungsmechanik), ideally also Advanced Fluid Mechanics (Fortgeschrittene Strömungsmechanik).

Learning outcome, core skills
After attending this module the student will understand state-of-the-art concepts and methods of gasdynamics and its applications in engineering sciences. The student will be in a position to analyse complex problems by selecting an appropriate approach to solving the problem and by applying well established solution methods. Additionally, the student will have the ability to transfer the learned skills into solving new problems.

Contents
a)
- Recapitulation of the basic concepts of fluid mechanics and thermodynamics
- Conservation laws
- Speed of sound and Mach-number
- Normal and oblique shock waves
- Expansion waves
- Lift and drag in supersonic flow
- Method of characteristics
- Compressible potential flow
- Numerical results

Educational form / Language
a) Tutorial (2 SWS) / Lecture (2 SWS) / German / English

Teaching mode
• Oral examination 'Gasdynamics' (20 Min., Part of modul grade 100 %, Oral exam in English or optionally in German)

Requirements for the award of credit points
Passed module exam: Oral exam

Module applicability
MSc. Mechanical Engineering

Weight of the mark for the final score
Percentage of total grade [%] = 5 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.
Further Information Manuscripts for lecture and exercise are available in both English and German. Also, the entire module will be made available in German as a video stream via Moodle. Further literature will be recommended during the lecture.

Geothermal Drilling Engineering und Subsurface Technologies

Geothermal Drilling Engineering und Subsurface Technologies

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	9 Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Geothermal Drilling Engineering and Subsurface Technologies	a) 4 SWS (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr. rer. nat. Rolf Bracke

a) Prof. Dr. rer. nat. Rolf Bracke

Admission requirements

Recommended previous knowledge: English language skills: "Test of English as a Foreign Language" (TOEFL): the test result in the internet version (iBT) should be at least 80 points, or "International English Language Testing System" (IELTS): minimum overall score "6" ("academic").

Learning outcome, core skills

The course gives an introduction to the principles of conventional and advanced deep drilling technologies and of production and reservoir engineering technologies. Students learn how to plan a drilling project including wellbore planning and selection of toolings and devices.

Knowledge:

- Fundamentals of deep drilling systems
- Drilling tooling
- Well and casing stability
- Site management skills
- Mud circulation
- LWD / MWD techniques
- Reservoir characterisation and testing

Abilities:

- Explain the main methods and parameters of drilling technology
- Describe potential drilling problems
- Define the composition of the cost structure of a drilling project
- Calculate casing designs

Competences:

- Develop deep drilling and production concepts,
- Explain the main methods and parameters of drilling technology,
- Describe potential drilling problems,
- Name major advanced drilling technologies,
- Define the composition of the cost structure of a drilling project.
- Name hydraulic test methods,

- Describe reservoir test principles,
- Define the parameters of a conceptual reservoir model.
- Tell principles of resource management,
- Calculate simple production parameters.
- Define pumping systems for specific applications,
- Describe the processes in the borehole while pumping,
- Name the damage mechanisms of downhole pumps.
- Describe the hydrochemically induced failure processes in the borehole while pumping.

Contents

a)

- Deep drilling basics; mechanical rock destruction process
- Drilling techniques and process
- Rotary drilling, percussion drilling, directional drilling
- Innovative and unconventional drilling techniques (thermal, hydraulic, coiled tubing)
- Drilling specific laboratory analysis
- Mud logging
- Health, safety issues and environmental impacts of drilling projects
- Pumping the reservoir
- Test procedures and low-temperature reservoir modelling
- Reservoir Engineering

Educational form / Language

a) Tutorial (1 SWS) / Lecture (3 SWS) / English / German

Examination mode

• Hausarbeit 'Geothermal Drilling Engineering and Subsurface Technologies' (40 Std., Part of modul grade 100 %, Homework as group work (in small groups) on various topics with subsequent presentation and discussion.)

Requirements for the award of credit points

- Passed final module examination: Term paper

Module applicability

MSc. Mechanical Engineering

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

Geothermal Energy Systems Geothermal Energy Systems					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8 Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Geothermal Energy Systems			**Contact hours** a) 4 SWS (60 h)	**Self-study** a) 90 h	**Frequency** a) each summer

Module coordinator and lecturer(s)
Prof. Dr. rer. nat. Rolf Bracke
a) Prof. Dr. rer. nat. Rolf Bracke

Admission requirements
Recommended previous knowledge: English language skills: "Test of English as a Foreign Language" (TOEFL): the test result in the internet version (iBT) should be at least 80 points, or "International English Language Testing System" (IELTS): minimum overall score "6" ("academic").

Learning outcome, core skills
The students know the fundamentals of energy conversion systems such as electricity generation from geothermal resources at low and at high enthalpy. They describe the function of the components of a power plant and understand the thermodynamics of fluid and steam cycles. They are able to design simple district heating networks and develop concepts for industrial applications for infrastructural and agricultural uses.

Kenntnisse:

- Components of a hydrothermal system
- Methods of enhancing geothermal reservoirs
- Reservoir principles for thermal water generation
- Schematic flow and temperature / entropy processes for geothermal plants
- Equipment for plants for electricity generation from steam and binary cycles and for direct uses
- Estimate the environmental and social impacts of geothermal projects

Fertigkeiten:

- Define the elements of thermodynamics
- Formulate the laws of thermodynamics
- Recite principles of the conversion of heat to work
- Distinguish entropy from exergy

Kompetenzen:

- Explain the structure and dimensions of the earth and the related heat potential,
- Give an outlook to the expected major future applications of geothermal energy.
- Name the main sources and amounts of heat deriving from the subsurface,
- Explain the temperature distribution inside the earth over space and time,
- Distinguish between the nuclear, thermal and solar heat sources within the earth´s structure and their sustainability,

- Define the hydraulic characteristics of geothermal systems,
- Differentiate the temperature versus depth parameters of low temperature fields and sedimentary basins.
- Describe the main technical solutions for direct, indirect and combined electricity and heat production uses,
- Propose possible applications for available resource temperatures.
- Describe the interactions of geothermal energy conversion systems: reservoir-well-piping-plant-reinjection
- Match the different power plant types and technical applications to corresponding reservoir conditions
- Identify the components of heat conversion technologies
- Develop technical solutions for given reservoir conditions, and regional or local energy demands.
- Compare the different cooling energy sources and choose the right cooling system for a site,
- Name the main elements for transmission and urban underground pipeline systems,
- Define the impacts of plants on the environment,
- Illustrate the phases and cumulative costs at various stages of development,

Contents

a)

- Global geothermal resources
- Elements of thermodynamics, fluid mechanics, and heat transfer applied to geothermal energy conversion systems
- Power plant technologies based on flash steam, direct steam, binary conversion systems, and hybrid systems
- Cooling technologies
- District heating networks and direct uses
- Pumping the reservoir
- Hybrid uses (water desalination)
- Mine water applications
- Corrosion and scaling processes
- Social and environmental impacts
- Case studies
- Economics, finance, and risk analysis of a geothermal project

Educational form / Language

a) Tutorial (1 SWS) / Lecture (3 SWS) / English / German

Examination mode

• Written exam 'Geothermal Energy Systems' (60 Min., Part of modul grade 100 %, Optional term paper to obtain bonus points for the written exam (40 hours, max. 10 pages, processing time 4 weeks, deadline will be announced at the beginning of the semester) If the number of participants is <= 10, the examination can also be conducted orally.)

Requirements for the award of credit points

Passed final module examination: Written exam

Module applicability

MSc. Mechanical Engineering

Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information

Introduction to Three-dimensional Materials Characterization Techniques

Introduction to Three-dimensional Materials Characterization Techniques

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	9th Sem.	1 semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Introduction to 3D Materials Characterization Techniques	a) 4 SWS (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)
Prof. Dr. Tong Li
a)

Admission requirements
none

Learning outcome, core skills
By completing the course, students gain insight into a range of three-dimensional nanoscale and atomic scale material characterization techniques, e.g. 3D x-ray microscopy, electron tomography and atom probe tomography. They can describe the working principles of each technique in detail, summarize applications in a vast of applications, such as engineering alloys, catalyst materials, semiconductors, etc. and solve scientific questions related to material science by using three-dimensional material characterization techniques. Additionally, students will understand three-dimensional nanoscale and atomic scale material characterization methods, which are currently extremely important in both industry and academia, and achieve some basic hands-on experience on sample preparation and sample analysis on one of these techniques (depends on the availability of instrument).

Contents
a)
- 3D Energy-dispersive X-ray spectroscopy
- 3D-Field ion microscopy
- Atom probe tomography
- Electron tomography
- X-ray tomography
- Focused ion beam slicing/scanning electron microscopy

Educational form / Language
a) Seminar / Lecture with tutorial / English / German

Examination mode
• During the semester each student will be assigned a current topic on which the student has to write a five-page report and give a talk (Percentage of the module grade 100 %)

Requirements for the award of credit points
passed module examination: semester assignments (Submission of report and holding of seminar talk)

Module applicability
- MSc. Mechanical Engineering

- MSc. Sales Engineering and Product Management
- MSc. Materials Science and Simulation

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

<table>
<tr><td colspan="6">Masterarbeit
Master's Thesis</td></tr>
<tr><td>Module number</td><td>Credits
30 CP</td><td>Workload
900 h</td><td>Semester[s]
3. Sem.</td><td>Duration
1 Semester[s]</td><td>Group size
no limitation</td></tr>
<tr><td colspan="3">Courses
a) Masterarbeit</td><td>Contact hours</td><td>Self-study
a) 900 h</td><td>Frequency
a) each Sem.</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Prof. Dr.-Ing. Andreas Kilzer
a) Prof. Dr.-Ing. Andreas Kilzer</td></tr>
<tr><td colspan="6">Admission requirements
Compulsory, compulsory elective and elective modules amounting to at least 50 CP (a maximum of 40 CP is still missing for a successful degree) from the Master's degree programme and any conditions imposed upon admission must have been passed.</td></tr>
<tr><td colspan="6">Learning outcome, core skills
The Master's thesis should show that the candidate is able to independently work on a challenging problem in mechanical engineering using scientific methods within a given period of time.
On a higher level the Master's thesis pursues the following objectives:
• The students are familiar with the current state of modern engineering research in the area of their major field of study.
• The students are familiar with the most modern methods and procedures of engineering sciences/ mechanical engineering in the area of their major field of study and know application examples.
• The students are able to model and solve complex engineering problems (if necessary interdisciplinary), as well as develop and implement their own approaches.
• The students can transfer knowledge/skills to concrete mechanical engineering/engineering problems.
• Students can transfer knowledge/skills to concrete and new problems.
• Students possess enhanced social competences relevant to their training, with a particular focus on independence and initiative</td></tr>
<tr><td colspan="6">Contents
a)
Various topics from the Master's programme, typically based on the chosen focus or the research areas of the supervising university teacher. Assignments are always formulated by university teachers and should reflect the scientific standard of the degree programme; if necessary, suggestions for topics from students can be taken into account. Both theoretical and experimental tasks can be worked on.</td></tr>
<tr><td colspan="6">Educational form / Language
a) Abschlussarbeit / German</td></tr>
<tr><td colspan="6">Examination mode
• Abschlussarbeit 'Master's Thesis' (900 Std., Part of modul grade 100 %)
• Intemediate or final presentation (approx. 30 minutes)</td></tr>
<tr><td colspan="6">Requirements for the award of credit points
• Passed final module examination: Final paper
• Successful intermediate or final presentation</td></tr>
</table>

Module applicability MSc. Mechanical Engineering
Weight of the mark for the final score Percentage of total grade [%] = 30 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information The Master's thesis can also be written in English.

Materials for Aerospace Applications

Materials for Aerospace Applications

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	9th Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Materials for Aerospace Applications	a) 4 SWS (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Marion Bartsch

a) Prof. Dr.-Ing. Marion Bartsch

Admission requirements

Recommended previous knowledge: recommended are basics in materials science and solid mechanics and english skills B1

Learning outcome, core skills

After successful completion of the module students can

- recapitulate which high performance materials and material systems are used for aerospace applications, how they are manufactured, and which microscopic mechanisms control their properties
- explain and apply procedures for selecting and developing material systems for aerospace components, considering the specific requirements
- decide which characterization and test methods to apply for qualifying materials and joints for aerospace applications and know how lifetime assessment concepts work
- draft work flows from data acquisition to certification of aerospace components
- communicate, using technical terms in the field of aerospace engineering in English

Contents

a)

The substantial requirements on materials for aerospace applications are „light and reliable“, in most cases for extreme service conditions. Therefore, specially designed materials and material systems are in use. Manufacturing technologies and characterization methods for qualifying materials and joints for aerospace applications will be discussed. Topics are:

- loading conditions for components of air- and space crafts (structures and engines)
- selecting and developing materials and material systems for service conditions in aerospace applications (e.g. aero-engines, rocket engines, thermal protection shields for reentry vehicles, light weight structures for airframes, wings, and satellites)
- degradation and damage mechanisms of aerospace material systems in service
- characterization and testing of materials and joints for aerospace applications
- concepts and methods for lifetime assessment
- data handling from acquisition to certification of aerospace components

Educational form / Language

a) Lecture with tutorial / English / German

Examination mode

• Written exam 'Materials for Aerospace Applications' (120 Min., Part of modul grade 100 %)

Requirements for the award of credit points

Passed module examination: Written exam

Module applicability

- MSc. Maschinenbau
- MSc. Sales Engineering and Product Management

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

script in English, additional literature announced during lecture

Multiscale Mechanics of Materials Multiscale Mechanics of Materials					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9th Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Multiscale Mechanics of Materials			**Contact hours** a) 4 SWS (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Dr. Alexander Hartmaier
a) Dr. Rebecca Janisch

Admission requirements
Recommended previous knowledge: keine

Learning outcome, core skills
Students possess a fundamental understanding of the multiscale nature of the mechanical behaviour of materials and of the different approaches to take this into account in mechanical modelling of microstructures. They can identify the relevant length- and timescales of the microscopic processes that lead to meso-/macroscopic structure-property relationships. The students understand the principles of effective theory construction, coarse graining and homogenisation methods, and they can apply them to identify, analyse and model multiscale problems, such as plastic deformation, hardening behaviour, and fracture of microstructures. They are familiar with state of the art numerical and theoretical scale-bridging modelling methods. They can apply numerical tools on different length scales, and understand the underlying principles (atomistic modelling, discrete dislocation dynamics, crystal and continuum plasticity). Finally, students build up the skill to independently develop scale- bridging models that integrate all necessary scales and employ these models to describe and predict mechanical properties of materials under given conditions.

Contents
a)
- Introduction to problems in materials mechanics that involve multiple length and time scales
- Overview on concepts of concurrent and hierarchical multiscale modeling of materials
- Principles of effective theory construction and its realisability in numerical modeling (extracting and passing information in hierarchical models); coarse graining and homogenisation
- Bridging scales in plasticity
- Bridging scales in fracture
- Numerical models and technical aspects of hierarchical multiscale simulations (atomistic modeling, discrete dislocation dynamics, continuum and crystal plasticity)

Educational form / Language
a) Tutorial / Seminar / English / German

Examination mode
• Written exam 'Multiscale Mechanics of Materials' (120 Min., Part of modul grade 100 %, or oral exam (30 Min., wird zu Beginn der Lehrveranstaltung festgelegt))

Requirements for the award of credit points
Passed final module examination: Oral exam or written exam

Module applicability

- MSc. Maschinenbau
- MSc. Sales Engineering and Product Management
- MSc. Materials Science and Simulation

Weight of the mark for the final score

Percentage of total grade [%] = 5 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).

DIV: The values can be taken from the table of contents.

Further Information

Numerical Gasdynamics for Propulsion and Power

Numerical Gasdynamics for Propulsion and Power

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	8th Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Numerical Gasdynamics for Propulsion and Power	a) 4 SWS (60 h)	a) 0 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr. Francesca di Mare

a) Prof. Dr. Francesca di Mare

Admission requirements

Recommended previous knowledge: Prerequisites for a successful participation to the lectures: Gasdynamics Thermodynamics Numerical Mathematics Fluid Mechanics

Learning outcome, core skills

After successfully completing the course the students master all theoretical and numerical tools to derive and analyse the mathematical model governing the flow of a compressible gas mixture. Furthermore, they understand how a flow solver for compressible fluids should be constructed. Particularly:

- The students understand the physical principles and can translate them in a mathematical model
- The students understand the the most relevant aspects of the flow of compressible fluids and are capable of making the correct assumption to simplify the corresponding mathematical models
- The students can translate mathematical models In a computed programme in a a structured and logical manner
- The students can assess the efficiency and accuracy of the programmed solver and the correctness of the results
- The students can design procedures to verify and validate the numerical results

Contents

a)

· Review of the fundamentals of Fluid Mechanics, Gasdynamics and Thermodynamics

- Derivation of the conservation equations (Mass, Momentum and Energy) in differential form
- Forms of the energy equation
- Non-dimensional form of the conservation equations
- Euler and Navier-Stokes Equations

· Classification of the conservation equations (elliptic, hyperbolic, parabolic)

· Definition of total quantities

· Thermal and caloric state equations and thermodynamic relations

· State variables

· Variable transformation and jacobian matrices

· Weak formulation of the conservation equations: discontinuities

- Example: advection equations

· Fundamentals of the spatial and temporal discretisation of hyperbolic problems · Numerical treatment of dicsontinuities considering the example of the advection equation • Varisou schemes and formulations (Roe, Lax-Wendroff, etc.) · Numerical treatment if the 1D Euler equations • Ideal gas model • Thermally perfect gas model · Boundary conditions · Theoretical formulation and implementation · Stability and error analysis
Educational form / Language a) Tutorial (2 SWS) / Lecture (2 SWS) / English
Examination mode • Written exam 'Numerical Gasdynamics for Propulsion and Power' (120 Min., Part of modul grade 100 %, If the number of participants is less than 5, the examination can also be conducted orally.)
Requirements for the award of credit points Successfully passed examination (written exam)
Module applicability MSc. Maschinenbau Master of Science Mechanical Engineering
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information The final mark consists exclusively of the examination mark. The lecture notes will be provided in english

<table>
<tr><td colspan="6">Numerical Methods for Internal Aerodynamics
Numerical Methods for Internal Aerodynamics</td></tr>
<tr><td>Module number</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Semester[s]
8th Sem.</td><td>Duration
1 Semester[s]</td><td>Group size
no limitation</td></tr>
<tr><td colspan="3">Courses
a) Numerical Methods for Internal Aerodynamics</td><td>Contact hours
a) 4 SWS (60 h)</td><td>Self-study
a) 0 h</td><td>Frequency
a) each summer</td></tr>
</table>

Module coordinator and lecturer(s)

Prof. Dr. Francesca di Mare

a) Dr.-Ing. Mohammed Sayyari

Admission requirements

Recommended previous knowledge: Calculus: integration, partial derivatives, Taylor Series, and coordinate systems Linear Algebra: solving linear systems Mechanics: momentum and force Thermodynamics: heat and energy Fluid mechanics: compressibility, laminar and turbulent flows, Navier-Stokes Equations Programming background: Python, matlab, etc.

Learning outcome, core skills

Completing the course successsfully, the student understands the principles of computer simulations for dynamic systems from the numerical point of view. This allows the student to analyze, derive, and implement a simulation of a flow model in a number of methods.

- The student understands the principles of discretization for conservation laws, in particular, equations of flow, and is able to identify the method/approach used in the simulation.
- The student analyzes and implements a workflow for a simulation using a numerical method/ approach, with the ability to judge the accuracy and stability of their implementation.
- The student recognizes the difficulties and appropriate setups for internal flows.

Contents

a)

- Review of important models in fluid mechanichs and thermodynamics: mass, heat, and momentum
- Review of important concepts in partial differencial equations: equation types and conservation laws
- Finite-difference method:
  # Order of approximation
  # Boundary conditions
  # Solving the linear system
- Finite-volumes method:
  # Volume average
  # Interface interpolation
  # Flux limiters
- Time discretization schemes:
  # Order of approximation
  # Implicit and explicit schemes

Multi-step and multi-stage schemes

Courant-Friedrichs-Lewy stability condition

- (Optional) Advanced topics:

Multi-grid method

Finite-element method

Optimization based simulation: physics-informed neural network

Educational form / Language
a) Tutorial (1 SWS) / Lecture (3 SWS) / English

Examination mode
• Written exam 'Numerical Methods for Internal Aerodynamics' (120 Min., Part of modul grade 100 %)
• Homework exercises (optional bonus points for the written exam are possible if the exercises are completed before the written exam).

Requirements for the award of credit points
Passed final examination: Written examination

Passed homework exercises

Module applicability
no information

Weight of the mark for the final score
Percentage of total grade [%] = 5 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).
DIV: The values can be taken from the table of contents.

Further Information

<table>
<tr><td colspan="6">Process Simulation of Energy Plants
Process Simulation of Energy Plants</td></tr>
<tr><td>Module number</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Semester[s]
9th Sem.</td><td>Duration
1 Semester[s]</td><td>Group size
45</td></tr>
<tr><td colspan="3">Courses
a) Prozesssimulation energietechnischer Anlagen</td><td>Contact hours
a) 4 SWS (60 h)</td><td>Self-study
a) 90 h</td><td>Frequency
a) each winter</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Prof. Dr.-Ing. Roland Span
a) Prof. Dr.-Ing. Roland Span</td></tr>
<tr><td colspan="6">Admission requirements
Knowledge with regard to the thermodynamic analysis of processes and plants in energy technologies, which can typically be taken for granted after completion of a Bachelor course with an appropriate extent of content relevant for energy technologies. No specific preconditions for participation.</td></tr>
<tr><td colspan="6">Learning outcome, core skills
After successful completion of the module
Building on fundamental knowledge regarding processes in energy technologies, students are able to model existing and new (discussed in the scientific literature) processes using modern simulation tools,
Students can assess power and efficiency of plants and processes in energy technologies and can identify influential parameters,
Students can analyse and assess the operating behaviour of real and hypothetical processes and plants in energy technologies,
Students can explain and assess the relevance of specific parameters of a process on a high level of abstraction based on parameter studies,
Students know the mathematical and thermodynamic foundations of process-simulation software,
Students can use advanced simulation tools to solve complex tasks,
Students can assess the performance and limits of simulation tools and can critically evaluate their performance (advantages and disadvantages).</td></tr>
<tr><td colspan="6">Contents
a)
Starting from the manual evaluation of processes in energy technology, which has been dealt with in different modules in pertinent Bachelor courses, the essential requirements for software for the simulation of processes in energy technologies are derived. The four main elements of such programs (graphical user interface, nonlinear equation solver, models for specific components, property package) are exemplarily introduced. Advantages and disadvantages of different solutions are discussed. The students set up models for simple processes (gas turbine and steam power-plants, ORC process, heat pump, solar power plant). The influence of the most important operating parameters is explained using the self-developed models as examples. Options for a systematic variation of operating parameters are introduced. As special case the application of process-simulation tools for an assessment of completely new processes (scientific application) and for the validation of measured process parameters (process control in operating plants) is discussed.</td></tr>
<tr><td colspan="6">Educational form / Language</td></tr>
</table>

a) Lecture with tutorial / German / English
Examination mode • Written exam 'Process Simulation of Energy Plants' (120 Min., Part of modul grade 100 %, In case less than 10 students are enrolled, the written exam can be replaced by an oral exam (30 minutes) with 60 minutes preparation of the questions at a computer (60 minutes))
Requirements for the award of credit points Passed module examination: written or oral exam, see above
Module applicability no information
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information Lecture and tutorials integrated (4 SWS); the module is offered in a bilingual mode. Supervision of the enrolled students can be offered in German and English in parallel.

Service Engineering

Service Engineering

Module number	Credits	Workload	Semester[s]	Duration	Group size
	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Service Engineering	a) 3 hrs./week (45 h)	a) 105 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr. Jens Pöppelbuß

a) Prof. Dr. Jens Pöppelbuß, Prof. Dr.-Ing. Bernd Kuhlenkötter

Admission requirements

Recommended previous knowledge: none

Learning outcome, core skills

After successful completion of the module,

- Students will be able to explain the opportunities and challenges of servitization in manufacturing, i.e., the transformation of manufacturing companies towards a growing service business.
- Students will be able to explain and differentiate between different types of industrial services and product-service systems.
- Students will be able to apply established frameworks and methods to analyze business models of firms and to develop exemplary approaches for innovative business models.
- Students will be able to apply customer-oriented methods to develop innovative service offerings.
- Students will be able to explain the importance of service quality and service excellence for business success.
- Students will be able to engage with current research results from the field of service engineering, communicate them to others and relate them to the state of the art of service research.

Contents

a)

- Servitization of Manufacturing
- Industrial services, customer solutions and product-service systems
- Digital services and smart services
- Business models
- Frameworks and methods for analyzing, developing and communicating business models (Business Model Canvas, St. Gallen Business Model Navigator).
- Service engineering/design/innovation methods (e.g., personas, customer journey mapping, service blueprinting)
- Service quality
- Procedure models for service engineering

Educational form / Language

a) Tutorial (1 SWS) / Lecture (2 SWS) / English

Examination modes

• Written exam 'Service Engineering' (120 Min., share of module grade 100 %, or oral exam (20 min., share of module grade 100%); type of exam will be announced at the beginning of the semester.)

• Assignments during the course: Presentation of an academic article from the field of service research (group performance, presentation duration 15 minutes, workload per group member: 10 hours; possible dates will be announced at the beginning of the semester).
Requirements for the award of credit points • Passed final module examination: written or oral examination • Passed study-related tasks: Paper presentation
Module applicability MSc. Sales Engineering and Product Management MSc. Mechanical Engineering
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information

<table>
<tr><td colspan="6">Solidification Processing
Solidification Processing</td></tr>
<tr><td>Module number</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Semester[s]
9th Sem.</td><td>Duration
1 Semester[s]</td><td>Group size
no limitation</td></tr>
<tr><td colspan="3">Courses
a) Solidification Processing</td><td>Contact hours
a) 4 SWS (60 h)</td><td>Self-study
a) 90 h</td><td>Frequency
a) each winter</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Prof. Dr. I. Steinbach
a) Prof. Dr. I. Steinbach</td></tr>
<tr><td colspan="6">Admission requirements
Recommended previous knowledge: keine</td></tr>
<tr><td colspan="6">Learning outcome, core skills
• Students will gain knowledge about different casting technologies, their applicationand specific characteristics.
• This includes the causes of casting defects and strategies to avoid defects.
• Furthermore, the Relationship of casting microstructure and process conditions will bediscussed and principles of alloy thermodynamics and solidification will be introduced</td></tr>
<tr><td colspan="6">Contents
a)
• History of metal casing, field of application and economic importance
• Shape-, pressure die-, continuous-, precision casting
• Directional solidification, rapid solidification, rheo- and tixo casing
• Mold material, molding and recycling· Mold filling and heat transfer (radiation and conduction)
• Simulation of mold filling, solidification and casting microstructureDuring the exercises practical casing and microstructure analysis is demonstrated in the laboratory and during excursions to different foundries specialized on different castingtechniques. The use of commercial software products for casting- and microstructureevolution simulation is demonstrated and trained on the computer</td></tr>
<tr><td colspan="6">Educational form / Language
a) Tutorial (2 SWS) / Lecture (2 SWS) / German / English</td></tr>
<tr><td colspan="6">Examination mode
• Written exam 'Solidification Processing' (120 Min., Part of module grade 100 %, or alternative oral exam (30 minutes) (Part of module grade 100 %))</td></tr>
<tr><td colspan="6">Requirements for the award of credit points
Passed final module examination: Written exam or oral exam</td></tr>
<tr><td colspan="6">Module applicability
no information</td></tr>
<tr><td colspan="6">Weight of the mark for the final score
Percentage of total grade [%] = 5 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).
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</table>

Further Information

Thermodynamics of Mixtures Thermodynamics of Mixtures					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8th Sem.	**Duration** Semester[s]	**Group size** no limitation
Courses a) Thermodynamics of Mixtures - Lecture b) Thermodynamics of Mixtures - Group Tutorials			**Contact hours** a) 3 SWS (45 h) b) 1 SWS (15 h)	**Self-study** a) 30 h b) 60 h	**Frequency** a) each summer b) each summer

Module coordinator and lecturer(s)
Prof. Dr.-Ing. Roland Span
a) Prof. Dr.-Ing. Roland Span
b) Prof. Dr.-Ing. Roland Span

Admission requirements
Recommended previous knowledge: Basics of thermodynamics, as they are commonly taught in Bachelor courses in Mechanical Engineering or equivalent subjects. No specific preconditions.

Learning outcome, core skills
After successful completion of the module

- Students can explain the specifics of thermodynamic properties of mixtures on a high level of abstraction,
- Students can challenge and assess new findings in the area of thermodynamic properties of mixtures,
- Students can utilize their knowledge on thermodynamic properties of mixtures to solve complex problems in energy and process engineering,
- Students can identify missing information in the field of thermodynamic properties, can access available information, and can assess found data critically,
- Students can assess the relevance of new research results in the field of thermodynamic properties of mixtures.

Contents
a)

- Calculation of thermodynamic properties for processes in energy technologies (equation of state models, properties of water and steam as special case, ideal mixture of real gases)
- Thermodynamic properties of mixtures, representation as excess properties and as partial molar properties
- Foundation of mixture effects on a molecular basis
- Models for the excess Gibbs-enegry and for the activity coefficient
- Phase equilibria with liquids, solids and gases
- Modern equations of state for mixtures

b)

Educational form / Language
a) Tutorial (1 SWS) / Lecture (3 SWS) / English
b) English

Examination mode
Written exam 'Thermodynamics of Mixtures' (150 Min., Part of module grade 100 %)

Requirements for the award of credit points Passed final module examination: Written exam
Module applicability no information
Weight of the mark for the final score Percentage of total grade [%] = 5 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18). DIV: The values can be taken from the table of contents.
Further Information

Turbulence Modelling Turbulence Modelling					
Module number	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9th Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Turbulenzmodellierung			**Contact hours** a) 4 SWS (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Romuald Skoda
a) Prof. Romuald Skoda

Admission requirements
Recommended previous knowledge: Fundamental of Fluid Mechanics (Grundlagen der Strömungsmechanik), ideally also Advanced Fluid Mechanics (Fortgeschrittene Strömungsmechanik), Numerical Methods for internal aerodynamics

Learning outcome, core skills
After attendance, the students understand recent turbulence models, which are implemented in common CFD software. They have expanded their competences of networked and critical thinking and are able to assess established methods with regard to accuracy, stability and effort. The students have achieved detailed, also interdisciplinary methodological competences and based on these, they can elaborate solutions of new problems.

Contents
a)
- Review of fluid dynamical and numerical fundamentals
- Overview over turbulence theory
- Introduction to Direct and Large Eddy Simulation
- Detailed presentation of statistical turbulence models (Eddy Viscosity and Reynolds Stress models)
- Hybrid models: Scale Adaptive (SAS) und Detached Eddy (DES) Simulation
- Wall treatment
- Laminar turbulent transition
- Model additives for stagnation flow, rotation and compressibility

Educational form / Language
a) Tutorial (2 SWS) / Lecture (2 SWS) / German / English

Examination mode
• Mündlich 'Turbulence Modelling' (45 Min., Part of modul grade 0 %, Oral exam in English or optionally in German)

Requirements for the award of credit points
Passed module exam: Oral exam

Module applicability
M.Sc. Mechanical Engineering

Weight of the mark for the final score
Percentage of total grade [%] = 5 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents (see also PO 2021 §18).
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Further Information

Manuscripts for lecture and exercise are available in both English and German. Also, the entire module will be made available in German as a video stream via Moodle. Further literature will be recommended during the lecture.