Module Description

Module Number: BM 1.1	**Module Name** **Material Science (Metallic and Polymer Materials)** **Responsible Person of the Module: Prof. Dr. Peter Starke**
Contents and Qualification Objectives	The micro- and meso-structures of metallic, polymer and composite materials are explained, and the related properties are described. The course delivers a general understanding of metallic, polymeric, and composite materials and the interaction of elastic or electromagnetic waves considered in NDT with the different kinds of materials structure. Qualification Objectives: The student should obtain a good understanding of materials behavior and properties at different scales.
Course and teaching methods	**Metallic Materials:** - Types of metallic materials and their properties - Structure of metals (starting from atomistic level, periodic tables, atomic bonds, materials packing, crystal systems and structures, atomic packing, theoretical density, locations in lattices, crystallographic directions and planes, planar densities, point, linear, planar and volume defects) - Ferrous and nonferrous metals: engineering materials overview, metals and alloys, ferrous metals, steel production, non-ferrous metals) - Intermetallic compounds, alloys, equilibrium diagram, aluminum alloys, - Lattice defects, magnetic domains, electronic and magnetic properties, hysteresis, Bloch walls and movements, influence of temperature, types of magnetism. - Elastic & plastic deformation: determination of deformation, stress-strain hysteresis loop, material's stress and strain life curve, influence of stress and strain control, plasticity in metals. - Strengthening mechanisms (grain size reduction, form solid solutions, solution alloying, precipitation including precipitates, heat treatment, strain hardening) - Creep: basics, creep curve, types of creep, factors affecting creep, mechanisms of creep, parameters, Larson-Miller parameter - Fatigue: basics, loading, S-N curves based on stress and strain, including analytic descriptions, very high cycle fatigue, effects of mean stress, loading type, load function, frequency, surface treatment and roughness, carbon content, residual stresses, grain size and temperature, size effects, statistical evaluation of S-N curves and endurance limit - Fracture: influencing factors, types of failure, mechanisms, testing, fracture resistance, influence of alloying, temperature, and strain rate, fractographic analysis, crack propagation analysis - Constitution and properties of steels, Al-based alloys, Ni-based alloys: Ashby maps **Polymers:** - Polymers: classification, formation, polymerization, molecular weight distribution, molecules, matrices, crystallinity, melting temperature, thermal analysis, calorimetry, molecular dynamics, free volume, glass transition, plasticizers, structural models - Formation of composites and basic mechanical properties: dimensional scales from macro to nano, interfaces, trans-crystalline layers, nano-particles, thermodynamics, particle synthesis, classification, elastic modulus calculation, epoxy, fillers, fibers and orientation, rule of mixtures, anisotropy, strength calculation, rupture, charpy impact, specific stiffness and stress, heat deflection, tear resistance - Fatigue and fracture: failure mechanics, fracture toughness, Griffith theory, design against fracture, crazing, local failure behavior, interparticle distances, **Composites:**

	- Natural and future engineering composites: biological materials, elasticity, nanocomposites, bone composites, rule of mixtures, stresses and strains, stiffness, fracture toughness, deformation, collagen, - Visco-elastic behavior: temperature dependence of stress vs. strain, elastic modulus, elastomers, mechanical models, creep, constant stress vs. constant strain, Boltzmann's superposition principle, stress relaxation, - Dynamic mechanical behavior: dynamic mechanical thermal analysis (DMTA), enforced damped vibration, complex modulus, effect of transition regions, experimental techniques, influence of cross-linking density, frequency, and curing, damping coefficients, storage modulus, - Manufacturing processes, - Fibers: asbestos, cellulose, collagen, silk, aramid, polyethylene, carbon, glass, SiC, Al_2O_3, metals, flexibility, strength, experimental characterization - Fiber architecture: particles, short fibers, laminates, fabrics (woven, knitted, braided, 3D, non-crimp), felts (non-woven), stitching - Matrices: metallic, ceramic, polymeric, thermosets; Resins: polyester, vinyl ester, epoxy; selection, curing - Mechanical characterization: overview, specimen preparation, testing equipment, tension, compression, shear, through-thickness testing, bearing, impact and damage tolerance. - Analysis I: structural definition, use of composites (i.e., in aviation), composites versus metals, materials selection, certification tests pyramid, classical laminate analysis, typical sizing criteria, sandwich components, golden rules for composite parts - Analysis II: behavior of laminae (stress-strain concepts in 3D, anisotropic elasticity, tensorial concepts indicial notations, plane stress concept, micromechanics), laminated composites (mechanics of plates, macromechanics , stress-resultants, limitations, structural mechanics, special classifications, compliances), strength and failure theories (strength of laminates, failure mechanics of composites, macromechanical failure theories, comparison of failure theories, Tsai-Wu criterion and others) - Processing: injection molding, spray lay-up, wet lay-up, hand lay-up, filament winding, pultrusion, resin transfer molding, prepreg manufacturing, lamination, vacuum bagging, autoclave consolidation, injection molding, compression molding, commingled yarns. - Manufacturing: manufacturing, processes and machines, practical applications (i.e., aeronautics), emerging techniques The contents will be taught through: - Lectures - In class exercises
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awards	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes. Pass of the module examination or higher will award the student 6 credit points.

Workload	The total workload of in-class lectures, self-study and examinations is 170 working hours. These 170 working hours are composed of 60 hours (80 lessons) of in-class lectures and 110 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the first semester and is taught in different blocks over the duration of the semester.
Recommended Literature	WILLIAM D. Callister, Jr.: Fundamentals of Materials Science and Engineering - An Interactive e. Text, 2008 WILLIAM D. Callister, Jr. and RETHWISCH, David G.: Materials Science and Engineering - An Introduction, 10th Ed., 2018 INAGAKI, Michio and KANG, Feiyu: Materials Science and Engineering of Carbon – Fundamentals, 2nd Ed., 2014 GRELLMANN Wolfgang, SEIDLER Sabine: Polymer Testing, 2nd Edition, Hanser 2013 CHAWLA Krishan K.: Composite Materials, 3rd Edition, Springer 2012 SCHÜRMAN Helmut: Konstruieren mit Faser-Kunststoff-Verbunden, 2nd Edition, Springer 2007 COWIE, J.M.G.: Polymers: Chemistry and Physics of Modern Materials, International Textbook Company, Aylebury, 2008 HIEMENZ, P.C.: Polymer Chemistry: The Basic Concepts, Marcel Dekker, Inc., New York, 2007 Sol-Gel Nanocomposites (Eds. M. Guglielmi, G. Kickelbick, A. Martucci), in: Advances in Sol-Gel Derived Materials and Technologies (Series Eds. M.A. Aegerter, M. Prassas), Springer, New York, 2014

Module Number: BM 1.2	**Module Name** **Measurement Techniques** **Responsible Person of the Module: Prof. Dr. Frank Walther**
Contents and Qualification Objectives	The module covers the physical and electrical basics of different measurement technology, techniques and instruments, and the principles of their operation and application. The second part of the module deals with the statistical treatments of measuring results, measuring error, error propagation and reliability. <u>Qualification Objectives:</u> The student should: - Understand on how to configure a measurement system - Demonstrate the ability to set up an operational measurement system in practice
Course and teaching methods	- Fundamentals: terms, data logging, measurement, deviation & uncertainty, daily life measurement, industrial measurement, measurement chains, signal processing (Fourier analysis) - Measurement methods & sensors: definitions & classification, active vs. passive, mechanical, thermal, resistive, capacitive, inductive, piezoelectric, magnetic, acoustic, x-ray - Production measurement technology: fundamentals, production processes, tolerances, dimension-, shape- & position-measurement, surface measurement, micro- and nano-measurement - Materials and component testing: fundamentals, microscopy, hardness, static/creep, quasistatic, impact, cyclic/fatigue - Statistical analysis and test planning: fundamentals, measurement deviations, stochastics, error propagation, statistical test planning - Data acquisition & control: overview, handling LabVIEW, implementation of virtual inspections (VI), data acquisition, sub-Vis and formula nodes, myDAQ and LabVIEW The contents will be taught through: - Lectures - Practical lab work - Exercises
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for the successful participation in Term 2.
Conditions for credit points awards	Credit points are awarded after successful participation in the module examination. The written module examination lasts 180 minutes. Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 170 working hours. These 170 working hours are composed of 60 hours of in-class lectures and 110 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the first semester and is taught as a block course over a period of four weeks.

Recommended Literature	DOEBELIN: Measurement Systems: Application and Design, McGraw Hill, New York, 2004 CZICHOS, SAITO, SMITH: Springer Handbook of Materials Measurement Methods, Springer, 2006 MEADOWS: Measurement of Geometric Tolerances in Manufacturing, CRC Press, 1998 National Instruments: Introduction to LabVIEW – 6-Hours Hands-On (ftp://ftp.ni.com/pub/devzone/tut/lv_86_in_6_hours.zip)

Module Number: BM 1.3	**Module Name** **Mechanics** **Responsible Person of the Module: Prof. Dr. Christian Boller**
Contents and Qualification Objectives	The module addresses the general understanding of mechanical phenomena to be considered in NDT. This mainly includes the physics of waves in general, sound and vibration based on mechanical waves in the terms of vibration modes, guided waves and acoustic bulk waves as well as the determination of stresses and strains, fatigue and fracture in materials and components. Topics such as damage tolerance design, fatigue, fracture, notches, linear elastic and elastic-plastic material behavior, load sequence analysis and generation, damage accumulation, fatigue life evaluation, crack propagation analysis, multi-axial stress –strain behavior, and much more will be addressed. Hardware aspects will be referred to as well. Students will be able to understand fatigue analysis and evaluation to a level that they are ready to use it along their daily work. It is attempted to generate a broad basic knowledge of the physical fundamentals of the acoustic and electromagnetic methods to be taught in Term 2 Qualification Objectives: The student should: - Get an understanding of sound and vibration as a basis to understand specific NDT modules due to follow in the next semester - Get a sound understanding of the role of stresses, strains, fatigue and fracture in structural components as a means to understand application needs for NDT.
Course and teaching methods	The module covers the following: **Sound and Vibration** **Lectures:** Elasticity; Oscillatory Motion; Fast Fourier Analysis; Undamped Free Vibration; Effective Mass; Viscously Damped Free Vibration; Harmonically Excited Vibrations; Multi Degree of Freedom Systems; Vibration Modes; Modal Analysis; Undamped String Vibrations; Damped String Vibrations; Waves in Fluids and Solids (Guided Waves) – Longitudinal & Shear Waves, Rayleigh & Love Waves; One-dimensional wave equation and solutions, Huygens Principle, Interference; Snell's Law; Reflection and Transmission; Wave Diffraction, Scattering and Absorption; Non-linearity in Vibrational Analysis; Wave Generation & Sound; Piezoelectric Effect and Acoustics; Electromagnetic Effect & Acoustics; Sound Pressure, Energy & Reaction on Interfaces; Acoustic Wave Sensing; Phased Array Principles; Wave Propagation with Finite Excitation Sources; Acoustic Waves in Anisotropic Media; Scattering in Acoustics. **Tutorials:** FFT Analysis; Coupled Vibrations; Modal Analysis; String Vibration Analysis; Guided Waves; Wave Propagation; Non-Linearity in Vibration Analysis; Piezoelectric Transducer Configuration; Electromagnetic Transducers; Acoustic Signal Sensing and Processing; Determination of Elastic Constants. **Fatigue and Fracture:** **Lectures:** Motivation: Damage tolerance design principle; Fatigue and fracture in materials; Stress-strain behavior in materials and structures; Fatigue: Constant amplitude fatigue testing; Notches; Load sequence analysis and generation; Random load fatigue testing; Fatigue life evaluation: Nominal stress approach; Fatigue life evaluation: Local strain approach; Fatigue influencing factors: mean stress, residual stress, multi-axial loading, surface roughness, corrosion, coatings, etc.; Fracture: Mechanical background; Stress intensity calculation; fracture toughness; crack propagation laws; Crack propagation calculations; mixed-mode cracking; stress-corrosion; plasticity; Tutorials: Stress-strain curve under tensile loading; stress-strain behavior under fatigue loading; notch effects; influence of ductility and non-linear stress-strain behavior on notches; determination of S-N-curves; load sequence analysis; fatigue life evaluation; determination of crack propagation data; crack propagation life evaluation.

	The contents will be taught through: - Lectures - Exercises
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awards	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes. Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 170 working hours. These 170 working hours are composed of 60 hours (80 lessons) of in-class lectures and 110 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the first semester and is taught in different blocks over the duration of the semester.
Recommended Literature	INMAN Daniel, 2014, *Engineering Vibration*, Pearson Education Inc. (4th Edition) ROSE Joseph L, 1999: *Ultrasonic Waves in Solid Media,* Cambridge University Press SCHIJVE Jaap, 2009: *Fatigue of Structures and Materials;* Springer

Module Number: BM 1.4	Module Name Numerical Methods & Signal Processing Responsible Person of the Module: Prof. Dr. Andrzej Klepka
Contents and Qualification Objectives	The course objective is to repeat the fundamentals and to strengthen the skills in the numerical mathematics as well as to develop fundamental knowledge in signal processing. Qualification Objectives: The student should: - Be able to understand the principles of numerical methods and signal process - Obtain the capability to perform signal processing and be able to handle FE models.
Course and teaching methods	**Lectures on Numerical Methods:** **Solution of transcendental equations:** Bisection method; fixed point method; Newton-Raphson method; **Eigenvalues & eigenvectors:** computation of eigenvalues; diagonalization of matrices; vector and matrix norms; matrix conditioning; direct resolution of a matrix system; iterative resolution of a matrix system; **Numerical differentiation and integration:** function interpolation; numerical differentiation; numerical integration; **Numerical solution of ordinary differential equations:** General principles of resolution; one-step numerical scheme; multistep numerical scheme. **Numerical solution of partial differential equations:** Generalities; finite element method; multistep numerical scheme **Lectures on Signal Processing;** **Studying signals:** Basic definitions; reminder on the theory of distributions; usual signals in signal processing; convolution of signals; correlation of signals; **Fourier series and Fourier transforms:** Decomposition of Fourier series; Fourier transform of signals with finite total energy; Fourier transform in the distribution sense; **Continuous linear systems and analog filtering:** Classification of systems; response of a LTI system to one input; frequency response of a LTI system; concept of filtering; ideal filters and physically realizable filters; classical realizable filters; **Sampling and quantification:** Ideal sampling; real sampling; anti-aliasing filtering; signal reconstruction; quantification; **Discrete signals and discrete linear systems:** Discrete signals; Fourier transform of signals with discrete time; discrete Fourier transform; discrete systems; temporal characterization of linear discrete systems; frequency response of linear discrete systems; **Discrete filtering:** Characterization of discrete filters; study of FIR filters; synthesis of IIR filters; **Wavelets.** **Laboratory on Numerical Simulation:** - Transcendental equations - Eigenvalues & eigenvectors - Numerical differentiation and integration - Numerical solution of ordinary differential equations - Numerical solution of partial differential equations **Laboratory on Signal Processing:** - Fourier series and Fourier transforms - Continuous linear systems and analog filtering - Sampling and quantification - Discrete signals and discrete linear systems

	- Discrete filtering - Wavelets The contents will be taught through: - Lectures - Exercises - Practical work with Matlab
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awards	Credit points are awarded after successful participation in the module examinations. The module examination consists of a written test (duration 120 min) Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 170 working hours. These 170 working hours are composed of 30 hours of in-class lectures, 30 hours of laboratory practice and 110 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the first semester and is taught in different blocks over the duration of the semester.
Recommended Literature	BHAGAWANDAS, P.; GREEN Lathi and Roger: Essentials of Digital Signal Processing SCHILLING, Robert J.; HARRIS Sandra L.: Fundamentals of Digital Signal Processing Using MATLAB ® ELLIOTT, Douglas: Handbook of Digital Signal Processing ORFANIDIS, Sophocles J.: INTRODUCTION TO Signal Processing TODD, Young and MOHLENKAMP Martin J.: Introduction to Numerical Methods and Matlab Programming for Engineers COLLINS, George W.: Fundamental Numerical Methods and Data Analysis

Module Number: BM 1.5	Module Name Introduction into NDT & Quality Management Responsible Person of the Module: Prof. Dr. Gerd Dobmann
Contents and Qualification Objectives	The module covers an overview of the different NDT techniques being applied and gives an insight into standardization and certification as well as quality management. The student will understand the fundamentals of the different NDT techniques considered and the role of and need for standardization, certification and quality management processes being involved in NDT as well as the quality management process in general. Qualification Objectives: The student should: - Understand the fundamental principles of different NDT techniques - Understand the role of standardization, certification and quality management - Possess the ability to apply quality management processes.
Course and teaching methods	**Introduction to NDT:** Fundamentals on electromagnetism; the six most important NDT techniques (visual, ultrasound, X-ray, eddy current, liquid penetrant, magnetic particles); further NDT techniques of relevance (acoustic emission, thermography, NMR, microwaves, laser optics, microscopy, impact-echo, potential drop, etc.); standardization in NDT; certification and training in NDT. **Quality Management:** **Introduction:** Definition of quality, principles of TQM, Quality council, continuous process improvement. **Statistical Process Control (SPC):** Statistical fundamentals, seven tools of quality, control charts for variables and attributes, process capability, six sigma concepts. **TQM Tools and Quality Systems:** Quality function deployment, house of quality, QFD process, Taguchi quality loss function, total productive maintenance TPM, ISO 9000, other quality systems, implementation of quality systems, quality auditing**. Introduction to Reliability:** Reliability and performance cost, quality and safety, stochastic processes, hazard rate, failure rate, probability and sampling, cumulative probability distribution function, data and distribution. **Reliability in Design and Life Cycle Costing:** Survival rate, bath-tube curve analysis of characteristics of failure regimes, design synthesis, reliability effort function, safety margin, allocation of reliability by AGREE, ARINC. The content will be taught through: - Lectures - Teamwork - Exercises
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awarded	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes. Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 170 working hours. These 170 working hours are composed of 60 hours of in-class lectures and 110 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.

Module Duration	The module is offered in the first semester and is taught in different blocks over the duration of the semester.
Recommended Literature	FEYNMAN, LEIGHTON, SANDS: The Feynman Lectures on Physics, Volume II - mainly electromagnetism and matter, 2013 Nondestructive Testing Handbook – Electromagnetic Testing (ET) – Vol V, 3rd Ed., 2004 DIN EN ISO 9001:2015 Quality management systems – Requirements DIN EN ISO 9000:2015 Quality management systems – Fundamentals and vocabulary DIN EN ISO/IEC 17025:2005 General requirements for the competence of testing and calibration laboratories TAYLOR & FRANCIS Ltd.: Total quality management and operational excellence, 5th Edition, July 2020 KRISHNAMOORTHI, K. S. and RAM KRSIHNAMOORTHI, V.: A First Course in Quality Engineering - Integrating Statistical and Management Methods of Quality, 3rd Edition, CRC PR INC, August 2018

Module Number: SM 2.1	Module Name Acoustic Methods Responsible Person of the Module: Prof. Dr. Philippe Guy
Contents and Qualification Objectives	The scope of the lectures is to impart complex knowledge about Non Destructive Testing (NDT) of construction elements and materials with the aid of acoustic methods. This also includes to learn, understand and apply advanced methods in ultrasonic testing with special emphasis on phased array and imaging techniques. The lecture contents include ultrasonic excitation, wave propagation in solids, beam focusing and directional intromission of ultrasound and deals with typical principles of ultrasonic transducers and measurement methods. It further includes phased array monitoring techniques including sampling phased array, air coupled ultrasonics, laser ultrasonics, guided waves and various methods of sensor signal imaging. The students are taught to select appropriate measurement methods for practical inspection tasks and design, modify and test adequate measurement set-ups. Qualification Objectives: - The student should: - Have a full understanding of acoustic principles applied in NDT - Have the ability to design, modify and test adequate measurement set-ups
Course and teaching methods	The module consists of the following parts: **Fundamentals of acoustic methods:** Application of ultrasound for the purpose of Non Destructive Testing (NDT), pulse echo technique ; Geometric considerations about refraction and reflection: Snell's Law of Refraction, focusing; Sound propagation in fluids and solids: Wave equation, material properties, vector equations, potentials, Hooke's Law, reflection, refraction, absorption, mode conversion; Ultrasonic transducers: transducer principle (piezoelectric effect), sound field in dependence of the measurement set-up, adaption of the measurement set-up **Ultrasonic test engineering**: Measurement methods, signal processing, material faults, A-, B-, C-mode visualization, synthetic aperture focusing technique (SAFT), AVG-diagram, time of flight diffraction technique (TOFD), test block for ultrasonic testing, ultrasonic microscopy; Transducers: single element transducers, arrays, construction of transducers, instruments and excitation electronics ;Sound emission test technique, impact-method; Structural Health Monitoring (SHM); Characteristics for the testing of concrete and austenite; Optimization of the measurement set-up for increasing resolution and signal quality **Specific acoustic techniq**ues: Phased array methods; Air coupled ultrasonics; Laser induced ultrasonics; Sampling phased array; Guided waves; Imaging Laboratory work / exercises: **Exercise:** physical fundamentals of ultrasonics Ultrasonic measurements with a test block Elementary sound field calculations with a simulation program for optimization of the measurement set-up Phased array monitoring, air coupled ultrasonics, guided waves The contents will be taught through: - Lectures - Exercises in class
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awards	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes. Pass of the module examination or higher will award the student 6 credit points.

Workload	The total workload of in-class lectures, self-study and examinations is 180 working hours. These 180 working hours are composed of 60 hours of in-class lectures and 120 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the second semester and is taught in different blocks over the duration of the semester.
Recommended Literature	ROSE, J.L.: Ultrasonic guided waves in solid media, Cambridge University Press, New York NY, 2014. BLACKSTOCK, David T.: Fundamentals of physical acoustics, Wiley-IEEE, 2000 ACHENBACH, Jan D.: Wave Propagation in Elastic Solids, North-Holland Publishing Co, 2nd Ed., ISBN 0720403251, 1987 BREKHOVSKIKH, Leonid M.: Waves in Layered Media, Academic Press, 1976 HARKER, Anthony H.: Elastic waves in solids with application to nondestructive testing of pipelines, Adam Hilger in association with British Gas, 1988 Advances in Phased Array Ultrasonic Technology Applications, Olympus NDT JOHNSON D. H. and DUDGEON, D. E.: Array Signal Processing Concepts and Techniques, Prentice Hall, Upper Saddle River, NJ, 1993. Introduction to Phased Array Ultrasonic Technology Applications, Olympus NDT

Module Number: SM 2.2	**Module Name** **Electromagnetic Methods** **Responsible Person of the Module: Prof. Dr. Gerd Dobmann**
Contents and Qualification Objectives	The module covers the physical and electrical engineering basics of magnetic, electro-magnetic, eddy current and microwave magnetic test methods, including hardware and applications. Structure and mode of action of the different micro-magnetic test systems and their application are covered. After participating in this module, students will be in the position to understand the possible applications of electromagnetic test methods and use those for flaw detection and material characterization. Qualification Objectives: The student should: - Understand the fundamental principles of electromagnetic methods - Be able to understand the possible applications of electromagnetic test methods - Use of electromagnetic methods for flaw detection and material characterization.
Course and teaching methods	The module consists of the following elements: **Electro-technical fundamentals:** Electric and magnetic fields; Induction law, Maxwell's equations; Electrical measurements and magnetic fields; Magnetic and electrical material properties and related microstructure and material flaws and discontinuities **Magneto-inductive and Magnetic Methods:** Magnetic sensors; Magnetic particle and Magnetic Flux Leakage method; Micro-magnetic techniques; DC-Potential-Drop technique; Electrical Impedance Spectroscopy; Nuclear magnetic Resonance. **Magneto-inductive and Magnetic Methods:** Eddy current testing; NDT using microwaves – Nuclear magnetic Resonance. The contents will be taught through: - Lectures - Exercises in class
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awards	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes. Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 180 working hours. These 180 working hours are composed of 60 hours of in-class lectures and 120 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the second semester and is taught in different blocks over the duration of the semester.
Recommended Literature	FEYNMAN, LEIGHTON, SANDS: The Feynman Lectures on Physics, Volume II - mainly electromagnetism and matter, 2013 Nondestructive Testing Handbook, 3rd Edition, Volume 5: Electromagnetic Testing, ASNT, 2004 ZOUGHI, R.: Microwave Non-Destructive Testing and Evaluation Principles, Kluver Academic Publishers, 2000

Module Number: SM 2.3	**Module Name** **Radiological Methods** **Responsible Person of the Module: Prof. Dr. Uwe Ewer**
Contents and Qualification Objectives	This module imparts the physical properties of several kinds of radiation and shows the relevant possibilities for materials characterization and testing of components. This includes typical methods, testing systems and practical applications. Students will be able to understand radiology to a level that they are ready to use it along their daily work. <u>Qualification Objectives:</u> The student should: - Understand the fundamental principles of radiological methods including equipment - Apply radiological methods for inspection and qualification purposes.
Course and teaching methods	The module consists of lectures covering the following: 1. **Radiographic and tomographic methods** **Physical properties of X-, γ- and particle rays**: Appearance, formation and physical parameters; Interaction of rays with matter, absorption and scattering; Methods for radiation detection **X-ray methods**: a) X-ray radiography: Concepts (film and digital methods) and equipment; Applications for testing of plants and electronic devices; b) 3D tomography; c) actual developments: Phase contrast method; Nano microscopy and tomography; X-ray fluorescence analysis and fluorescence tomography. **Neutron methods:** Neutron radiography and tomography. **Isotopes:** a) radioactive marking in technology and medicine; b) radiotracer methods: Resistance time measurements; Humidity distribution; Tomographic methods **Further methods:** application of positrons (PET) **2. Diffraction- und spectroscopic methods** **Physical properties of X--, γ- and particle rays**: Principles of phase analysis, texture- and stress determination **X-ray diffraction**: a) examples of phase and texture analysis; b) determination of residual stress in the laboratory by synchrotron radiation and with mobile systems; c) high resolving X-ray methods at monocrystalline materials **X-ray spectroscopic methods** (XPS, EXAF, EANES a.m.) **Neutron methods:** a) angle resolved and flight time method; b) neutron activation analysis **Further methods:** Disordered angle correlation; Mößbauer effect. The module is mainly devoted to knowledge transfer. Knowledge transfer requires presence of the student in class. Professional preparation and post processing is expected through self-study of scripts made available as well as references. The contents will be taught through: - Lectures - Exercises in class
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awarded	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes.

	Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 180 working hours. These 180 working hours are composed of 60 hours of in-class lectures and 120 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the second semester and is taught in different blocks over the duration of the semester.
Recommended Literature	CZICHOS, Horst: Handbook of Technical Diagnostics, Springer-Verlag Berlin, Heidelberg, 2013 HALMSHAW, Ron: Industrial Radiology, Theory and Practice, Chapman & Hall, London, 2nd Edition, 1995 BOSSI, Richard H.; ISSINGS, Frank A; WHEELER, George C.: Nondestructive Testing Handbook, Volume 4 "Radiographic Testing", ASNT, Columbus, 3rd Edition, 2002 HAUK, Viktor: Structural and Residual Stress Analysis by Nondestructive Methods Evaluation - Application - Assessment, Elsevier, 1997 KAK, Aninash C.; SLANEY, Malcolm: Principles of Computerized Tomographic Imaging- Society for Industrial and Applied Mechanics, 2001 (freely available in Internet) McKIE, Duncan and McKIE, Christine: Essentials of Crystallography, Blackwell Science Ltd 1986

Module Number: SM 2.4	Module Name Optical Methods Responsible Person of the Module: Dr. Wolfgang Habel
Contents and Qualification Objectives	The module is targeted at the fundamentals of optics and optoelectronics from a theoretical, numerical and experimental point of view. A major focus will be on applications in electronics. Hardware aspects will also be of significance. Students will be able to understand optoelectronics to a level that they are ready to use it along their daily work. Qualification Objectives: The student should: - Have an understanding of the fundamental principles of optical methods - Be able to use optical methods in practice
Course and teaching methods	The module consists of lectures covering the following: - Reflection, diffraction, scattering, - Lenses, interference, polarization; birefringence, - Radiation, photometry, black- body radiation, - Emission, absorption, - Visible light, principles of microscopy, contrast, techniques and systems, - Laser, generation, characteristics, techniques and systems, - Holography, Shearography, typical applications, - Infrared, active and passive use of radiation, technique and types of cameras, typical applications. - Optoelectronic imaging methods - image acquisition. - preprocessing and segmentation, - feature selection, classification - 3D-image acquisition by laser scanning The contents will be taught through: - Lectures - Exercises in class
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awarded	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes. Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 180 working hours. These 180 working hours are composed of 60 hours of in-class lectures and 120 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the second semester and is taught in different blocks over the duration of the semester.
Recommended Literature	GONZALEZ R.C. and WOODS R.E.: Digital Image Processing 4th Edition GONZALEZ Rafael C., WOODS Richard E. and EDDINS Steven L.: Digital Image processing using MATLAB HECHT, E.: Optics, 5th Edition, Addison Wesley Publishers, 2016 PEDROTTI Frank L., PEDROTTI Leno M.: Introduction to Optics, 3rd Edition,

	Pearson Education Ltd. UK, 2017 SANTOS J. L., FARAHI F.: Handbook of Optical Sensors, CRC Press, Taylor & Francis Group, 2018 The Optics Encyclopedia - Basic Foundations and Practical Applications, 5 Volumes, 1st Edition December 2003, Wiley-VCH, Berlin

Module Number: SM 2.5	**Module Name** **Thermal & Microscopical Methods** **Responsible Person of the Module: Dr. Mathias Ziegler**
Contents and Qualification Objectives	The module is targeted at the fundamentals of thermography and microscopy from a theoretical, numerical and experimental point of view. A major focus will be on applications in electronics. Principles and operating mode of systems for non-contact temperature measurement (pyrometer and thermography cameras) are described. Hardware aspects will also be of significant importance. Students will be able to understand thermography and microscopy to a level that they are ready to use it along their daily work. Qualification Objectives: The student should: - Possess a fundamental understanding of the principles and methods used in thermography and microscopy - Have the ability to apply techniques and systems related to thermography and microscopy
Course and teaching methods	The module consists of lectures covering the following: - Infrared and thermal testing - radiometric basics, photometric basics, infrared radiation detectors, - pyrometer, thermography - NDT applications **Microscopy:** - High resolution NDE methods based on acoustic and X-ray methods (ultrasonic microscopy, X-ray microscopy). - Optical microscopy Abbe limit, nearfield optical microscopy, micro and nano-Raman microscopy. - Electro-microoptical and analytical methods (SEM, TEM, micro probe, focused ion beam technique, scanning probe techniques (tunnelling microcopy, AFM, AFAM, MFM and derivatives) Lecturing in the morning followed by tutorials and lab classes in the afternoon; a sufficient period of self-study (around two weeks net) with possible consultancy by the lecturer will be given as a means for preparation for the written exam. The contents will be taught through: - Lectures - Exercises
Participation requirements	The general preconditions contained in the examination regulations need to be fulfilled. Prior to in-class lectures, literature recommendations are provided for self-study and reference. Students are recommended to study the contents prior to or during course participation. The literature contents are assumed to be known by students during the in-class lectures.
Availability and supply frequency of the module	The module is a requirement in the master's program “Non Destructive Testing” and is generally offered once a year. Mastering the course contents is a prerequisite for taking the modules in the semesters to follow.
Conditions for credit points awarded	Credit points are awarded after successful participation in the module examination. The written module examination lasts 120 minutes. Pass of the module examination or higher will award the student 6 credit points.
Workload	The total workload of in-class lectures, self-study and examinations is 180 working hours. These 180 working hours are composed of 60 hours of in-class lectures and 120 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.

Module Duration	The module is offered in the second semester and is taught in different blocks over the duration of the semester.
Recommended Literature	VOLLMER, K.-P., MÖLLMANN: Infrared Thermal Imaging: Fundamentals, Research and Applications, Wiley-VCH, 2017 ALMOND, D.P.; PATEL, P.M.: Photothermal Science and Techniques. Springer-Verlag, 1996 MALDAGUE, X.P.: Theory and Practice of Infrared Technology for Nondestructive Testing, John Wiley & Sons, 2001 SIEGEL, R.; HOWELL, J. R.: Thermal Radiation Heat Transfer, 7th Edition, Taylor and Francis, 2020 BREITENSTEIN, O.; WARTA, W.: LANGENKAMP, M.: Lock-in Thermography - Basics and Use for Evaluating Electronic Devices and Materials, 3rd Edition, Springer-Verlag, 2018 McPHERSON, J.W.: Reliability Physics and Engineering – Time to Failure Modeling, 3rd Edition, Springer-Verlag, 2019 EATON, Peter and WEST, Paul: Atomic Force Microscopy, Oxford University Press, 2018 REIMER, L., and HAWKES, P.W.: Scanning Electron Microscopy, Springer 2010 (Die Ausgabe von 2010 konnte nicht gefunden werden) REIMER, L., and KOHL. H.: Transmission Electron Microscopy, Springer 2010 (Die Ausgabe von 2010 konnte nicht gefunden werden) ATTWOOD, D.: Soft X-rays and Extreme UV Radiation, Cambridge Univ. Press 2012

Module Number: **SA 3.1**	**Module Name** **BC-Course** **Responsible Person of the Module: Dr. Ralf Holstein**
Contents and Qualification Objectives	The module represents the basis of a Level 3 certification in accordance with the German Society of NDT (DGZfP). It also applies to Level-2 inspectors as well as next generation leaders in the fields of inspection supervision, technical management, quality management or procurement officers. Following the high responsibility of a Level 3 inspector this module targets at providing a solid basic knowledge regarding NDT. The module is run over four weeks and consists of lectures, presentations, and exercises where a profound insight will be provided into ten NDT methods including practical applications based on real world examples. Topics regarding personnel, laboratory and materials management with respect to NDT are an add-on to be taught along the module as well. Qualification Objectives: The student should: - Have a profound insight into ten different NDT methods - Gain significant experience in the practical application of different NDT techniques
Course and teaching methods	The module consists of three parts denoted as M1 to M3: Part 1: Basic Principles of NDT (10 days) Compact overview on 4 surfaces based and 2 volumetric based procedures (M1) Certification of NDT-personnel in accordance with DIN EN ISO 9712 (M1) Materials science (M1) Part 2 + 3: Application, Development, Organization (5 + 5 days) Application specific selection and application of NDT procedures (M2) Comparisons and overviews; additional and more recent NDT procedures (M3) ASNT certification; accreditation and laboratory organization (M3) Teaching methods consist of lectures, hardware procedural presentations, exercises with lab character. The contents will be taught through: - Lectures - Laboratory experiments
Participation requirements	The general prerequisites set in the examination regulations need to be fulfilled. This includes successful accomplishment of all Basic Modules (BM) and Special Modules (SM).
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for the successful participation in Module SA-3.2 (Research Internship)
Conditions for credit points awarded	Credit points are awarded after successful participation in the module examination according to standing orders of DGZfP. This requires the following three exams to pass successfully: - Basis Exam: in accordance with minimum requirements of DIN EN 473 (BC 3 Q M1) - Studies Exam: Meets ASNT SNT-TC-1A requirements (BC 3 Q M2) - Final Exam: NDT management and accreditation (DGZfP-select) (BC Q M3) Pass of all module examinations or higher will award the student 15 credit points. Qualification certificate in accordance with DGZfP-select BC 3 Q
Workload	The total workload of in-class lectures, self-study and examinations is 440 working hours. These 440 working hours are composed of 150 hours of in-class lectures and 290 hours of individual work for course preparation and follow-up. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the third semester and is taught as a block course over a period of ten weeks.

Recommended Literature	All lecture materials are provided by DGZfP.

Module Number: SA 3.2	**Module Name** **Research Internship** **Responsible Person of the Module: Prof. Dr. Christian Boller**
Contents and Qualification Objectives	The module consists of hands-on research work to be performed within a major research institution such as BAM, Fraunhofer or any others through the lecturers of the course who perform qualified scientific and engineering work with R&D needs in the field of NDT. The topic to be worked on must be defined by the hosting institution and must include mainly work being related to NDT addressing the student's skills trained so far to be applied within a true operational environment. The topic must be described regarding the title, contents and outcome on no more than two pages clearly addressing the objectives and must be approved by the course director. Results of the research internship must be summarized in a research report and must be presented in front of an auditorium at the end of the semester. <u>Qualification Objectives:</u> The student should: - Get an insight into an NDT R&D environment - Perform work related to R&D in NDT - Obtain the ability to perform own NDT related R&D work
Course and teaching methods	There is no teaching taking place along this module
Participation requirements	The general prerequisites set in the examination regulations need to be fulfilled. This includes successful accomplishment of all Basic Modules (BM), the Special Modules (SM) and the DGZfP BC course.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents is a prerequisite for the successful participation in Module MT-4.1 (Master Thesis)
Conditions for credit points awards	Credit points are awarded after successful participation in the module examination. This consists of: A positive feedback in terms of the student's active participation from the local internship supervisor Provision of an internship report (10 pages written in the format of a scientific paper) and positively marked by the academic supervisor An oral public presentation of 15 minutes duration followed by 5 minutes of Q&A in front of an examination board. Pass of report and oral presentation and examination or higher to obtain 15 credit points.
Workload	The total workload of internship work, report writing, and oral presentation is 450 working hours. The time needed for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the third semester and lasts over a period of 12 weeks.
Recommended Literature	The literature depends on the topic of the research internship.

Module Number: AM 4.1	**Module Name** **Master´s Thesis** **Responsible Person of the Module: Prof. Dr. Christian Boller**
Contents and Qualification Objectives	The module consists of scientific work to be performed at the student's originating university or upon request by a major research institution such as BAM, Fraunhofer or any others through the lecturers of the course who performed qualified scientific and engineering work with R&D needs in the field of NDT. The topic to be worked on is proposed by the hosting institution and must be approved by the DIU scientific director of the program and must clearly address a scientific challenge in NDT. The topic must be described regarding the title, contents and outcome on no more than two pages clearly addressing the objectives. Results of the master thesis must be summarized in a research report and must be presented in front of an auditorium and an assessment committee at the end of the semester. Qualification Objectives: The student should: Be able to independently perform R&D work in the field of NDT
Course and teaching methods	There is no teaching taking place along this module
Participation requirements	The general prerequisites set in the examination regulations need to be fulfilled. This includes successful accomplishment of all Basic Modules (BM), the Special Modules (SM).and the DGZfP BC course.
Availability and supply frequency of the module	The module is a requirement in the master's program "Non Destructive Testing" and is generally offered once a year. Mastering the course contents regarding the basic and specific modules (BM & SM) as well as the specific action (SA) is a prerequisite for the successful participation in Module MT-4.1 (Master Thesis).
Conditions for credit points awarded	Credit points are awarded after successful participation in the module examination. This consists of: Provision of the master thesis (format defined in 'DIU Format Regulations for the Submission of a Master Thesis') and positively marked by the academic supervisors An oral public presentation of 30 minutes duration followed by no more than 20 minutes of Q&A in front of an examination board. Pass of report, oral presentation, and examination or higher to obtain 30 credit points followed by the double degree.
Workload	The total workload of research work, thesis writing, and oral presentation is 900 working hours. The time required for individual work may vary due to the previous knowledge that the students might have.
Module Duration	The module is offered in the fourth semester and lasts over a period of 23 weeks.
Recommended Literature	The literature depends on the topic of the master ´s thesis.