Elastic Metamaterials and Actuators for Space Applications

Educational subject description sheet

Basic information

Field of study AGH UST International Courses	**Didactic cycle** 2022/2023
Speciality All	**Subject code** POGJOS.A100000O.624edc6075b34.22
Department Generic subjects	**Lecture languages** English
Study level any level	**Mandatory** Elective
Study form Full-time studies	**Block** General Modules
Education profile General academic	**Subject related to scientific research** Yes
	USOS code 130-INT-xS-225

Subject coordinator	Paweł Paćko
Lecturer	Paweł Paćko, Francois Pigache

Period Winter semester	**Examination** Assessment **Activities and hours** Lecture: 8, Project classes: 22	**Number of ECTS points** 3.0

Goals

G1	Providing students with basic knowledge on wave dynamics in inhomogeneous elastic media
G2	Providing students with nomenclature related to wave propagation - frequency, wavenumber, dispersion, attenuation, bandgaps
G3	Providing students with basic knowledge on piezoelectricity, magnetostriction and shape memory alloys
G4	Providing students with knowledge goals and rules of design and analysis of actuators and energy harvesters

Subject learning outcomes

Code	Outcomes in terms of	Directional learning outcomes	Examination methods
Knowledge – Student knows and understands:			
W1	Students know and understand elastic waves physics and basic phenomena		Project
W2	Students know the piezoelectric and magnetostrictive effects and characteristics of shape memory alloys		Project
W3	Students know design principles for actuators and energy harvesters for space applications		Project
Skills – Student can:			
U1	A student can interpret and analyze dispersion properties and apply them for obtaining specific effects		Project
U2	A student can compose and adjust material properties and shape of a metamaterial in order to obtain desired dynamic properties		Project
U3	A student can design an actuator and/or energy harvester for space application, employing a metamaterial		Project
Social competences – Student is ready to:			
K1	Students are eager to work in groups/teams		Project
K2	Students are ready for team work and problem solving		Project

Programme content that ensure achieving learning outcomes for the module

Introduction to wave dynamics and metamaterials. Analysis of actuators and energy harvesters based on ordinary materials and metamaterials.

Calculation of ECTS points

Activity form	Average amount of hours* needed to complete each activity form
Lecture	8
Project classes	22
Preparation for classes	56
Student workload	**Hours** 86
Workload involving teacher	**Hours** 30

* hour means 45 minutes

Study content

No.	Course content	Subject learning outcomes	Activities
1.	Introduction to space as a challenging research area that requires unique solutions. New era materials and devices are critical for development of new, high-performance devices. Energy balance, both mechanical and thermal, is an important topic in this extreme environment. The goal of this lecture is to present new materials, namely metamaterials, in the context of their extraordinary properties with applications to novel sensing and actuation, energy harvesting, vibration, temperature protection and others. Introduction to metamaterials: new design paradigm, extraordinary applications. Dynamic properties of metamaterials. Introduction to wave dynamics: - the elastodynamic equation, boundary conditions and solutions (rods and beams), basic concepts (frequency, wavenumber, wave speed, group velocity), - dynamic properties of the elastodynamic equation – amplitude and phase characteristics (dispersion), - forced rod problem, solution methods, Green’s function, the concept of anisotropy and focusing	W1, U1	Lecture
2.	Introduction to waves in heterogeneous materials: - problem definition: partial solutions and boundary conditions (continuity), - Bloch waves, - dispersion and excitability, - bandgaps and their properties, comparison to the homogeneous case, - excitation in the bandgap. Extraordinary effective properties of metamaterials – negative mass and stiffness. Introduction to resonant metamaterials: - harmonic oscillator and impedance concept, - point impedance in a rod, - introduction to multiple scattering problems: solution strategy, reflection and transmission, - relation between impedance and characteristic transmission and reflection, - design objectives and methods, impedance modeling (impedance of continuous point scatterers), clusters of scatterers and their properties.	W1, U1, U2	Lecture

3.	Introduction to actuation and energy harvesting mechanisms. Actuator concepts, vibration damping and control mechanisms and energy harvesting. Design and properties requirement for actuators and energy harvesters in space. Piezoelectricity and application of piezoelectic effects in actuation and energy harvesting. Shape memory alloys and their characteristics - theory and applications. Magnetostriction. Basics of development of analytical models for piezoelectric devices - energy-based approaches. Eigenproblem for estimation of dynamic properties of actuators. Study of the impact of parameters change (geometrical or electrical parameters).	W2, W3, U3	Lecture
4.	Strategies for combining metamaterials in actuators and energy harvesters for space applications. Introduction of the continuity conditions. Methodologies to use the model for the dimensioning and optimisation of actuation devices.	W2, W3, U1, U2, U3	Lecture
5.	Analysis of basic dispersion phenomena - identification of bandgaps and one-wave bands. Analysis of characteristic parameters using examples of periodic metamaterials. Computation of band diagrams for 1D periodic phononic crystals.	U1, U2, K1, K2	Project classes
6.	Analysis of multiple scattering systems - reflection and transmission properties for various impedance models. Design of a metacluster with desired transmission and reflection properties.	U1, U2, K1, K2	Project classes
7.	Planning a metamaterial through its dispersion characteristics. Design of a metamaterial with pre-defined dispersion properties.	U1, U2, U3, K1, K2	Project classes
8.	Applying design principles for a bimorph cantilever structure in longitudinal displacement (1D model) with desired dynamic properties. Development of a computational model for a piezoelectric device (the bimorph cantilever in flexural displacement, 1D model) with required properties.	U2, U3, K1, K2	Project classes
9.	Applying metamaterial design in a piezoelectric device and estimation of its efficiency.	U1, U2, U3, K1, K2	Project classes
10.	Dimensioning and optimisation of the device for reduction of the distribution of the piezoelectic element and metamaterial setup for actuation and energy harvesting.	W3, U3, K1, K2	Project classes

Course advanced

Teaching methods:

Brainstorming, Project based learning, Problem based learning, Design thinking, Group work, Case study, Discussion, Multimedia presentation, Lectures

Activities	Examination methods	Credit conditions

Activities	Examination methods	Credit conditions
Lecture	Project	
Project classes	Project	Development and presentation of a group project.

Requirements and method of completing particular forms of classes

The course is evaluated based on a project developed during classes and student personal work.

Method of calculating the final grade

The final grade is given based on the project evaluation and intermediate knowledge checks.

Method and procedure for compensating for missed coursework resulting from student absence from classes

Students are required to catch up with all material presented during lectures and laboratories.

Entry requirements

The course is devoted to elastic metamaterials and actuators for space applications. The focus is on design and analysis dynamical response of extraordinary materials and their application to energy manipulation in actuators and energy harvesters.

Attendance requirements for particular classes, with indication whether student attendance is compulsory

A student should attend at least 50% of laboratory classes. In case of an absence, student is required to catch up and submit all project documents and fullfill all project's goals.

Literature

Obligatory

1. Ultrasonic Waves in Solid Media, J. Rose
2. Sensors and Actuators, D. A. Hall

Research and publications

Publications

1. Inverse grating problem: efficient design of anomalous flexural wave reflectors and refractors, P. Packo, A. N. Norris, D. Torrent, Physical Review Applied, 2019 vol. 11 iss. 1, art. no. 014023, s. 014023-1–014023-17.
2. Metaclusters for the full control of mechanical waves, P. Packo, A. N. Norris, D. Torrent, Physical Review Applied, 2021 vol. 15 iss. 1, s. 014051-1–014051-12.
3. Nonlinear multiple scattering of flexural waves in elastic beams: frequency conversion and non-reciprocal effects, A. Karlos, P. Packo, A. N. Norris, Journal of Sound and Vibration, 2022 vol. 527 art. no. 116859, s. 1-16.
4. Non-symmetric flexural wave scattering and one-way extreme absorption, A. N. Norris, P. Packo, Journal of the Acoustical Society of America, 2019 vol. 146 iss. 1, s. 873–883