WALTER D'AMBROGIO

Programme of "Meccanica delle Vibrazioni" "Mechanical Vibrations"		
Number of ECTS credits: 9 (workload is 225 hours; 1 credit = 25 hours)		
I0237, Compulsory **2nd Cycle in MECHANICAL ENGINNERING (Design track), 1st year , 1st semester**		
Teacher: **Prof. Walter D'Ambrogio**		
1	**Course objectives and Learning outcomes**	The goal of this course is to provide analytical, numerical and experimental tools necessary to perform a dynamical characterization of mechanical systems. On successful completion of this course, the student should have profound knowledge and be able to model, analyse and identify discrete and continuous vibrating systems.
2	**Dublin descriptors**	Topics of the module include: **Vibrations of single degree of freedom systems:** Complex representation of harmonic signals. Undamped and viscously damped free vibration. Forced harmonic vibration: dynamic amplification and phase diagram. Resonance. Response to base motion. Response to periodic excitation: Fourier series. Response to general excitation: time and frequency domain; step response, impulse response, convolution integral. Frequency response function: relation with impulse response. Structural damping. Frequency response functions: receptance, mobility and inertance. Vibration isolation: air springs. Measurement of vibration: seismic transducers; working principle of vibrometer and accelerometer; piezoelectric accelerometer. Non linearities in vibrating systems. **Vibration of multiple degree of freedom systems:** Kinetic and potential energy: mass and stiffness matrices. Dissipation function: damping matrix. Equation of motion. Free undamped vibration: eigenvalue problem, orthogonality and normalisation of eigenvectors. General solution of free problem: eigenvectors as mode shapes. Multiple eigenvalues, vibration of suspended rigid bodies. Forced vibration: dynamic stiffness matrix. Coupling of coordinates: principal coordinates. Modal analysis of undamped systems. Kinetic and potential energy in modal coordinates. Harmonic excitation: frequency response function in terms of modal parameters. General excitation: time and frequency domain. Modal analysis of damped systems. Proportional viscous damping. Non proportional viscous damping: state space formulation. Structural damping: proportional and non proportional damping. Frequency response function in terms of modal parameters: viscous and structural damping, proportional and non proportional damping. Rayleigh ratio: stationarity. Damped vibration absorber. **Vibration of continuous systems:** Transverse vibration of a string: equation of motion. D'Alembert solution; solution by separation of variables. Eigenvalue problem: fixed-fixed string, fixed-sliding string. Orthogonality and normalisation of eigenfunctions. General solution of free problem: initial conditions, physical meaning of the eigenfunctions. Axial vibration of rods: equation of motion. Eigenvalue problem: free-free rod, fixed-free rod. Torsional vibration of shafts: equation of motion, eigenvalue problem. Bending vibration of beams: equation of motion. Free vibration. Bending waves in beams and plates. Solution by separation of variables. Eigenvalue problem. Orthogonality and normalisation of eigenfunctions. General solution of free problem: initial conditions, physical meaning of the eigenfunctions. Forced vibration: modal analysis. Lumped excitation. Harmonic excitation: lumped harmonic excitation, frequency response function. Approximate solutions: Rayleigh method, Rayleigh-Ritz methods, comparison with finite element method; forced problems: assumed modes method, Galerkin method, collocation method. **Signal analysis:** Analog to digital conversion: effect of the number of bits. Sampling: Fourier transform of a sampled signal. Aliasing: minimum sampling frequency as function of the maximum frequency of the signal. Reconstruction theorem (Shannon). Discrete Fourier transform. Effect of signal truncation: leakage and

		smearing. Minimisation of leakage: time windowing. **Modal testing:** Physical model, modal model, response model. Aim of modal testing. Input-output tests (experimental determination of frequency response function); output-only tests. Excitation tools: electrodynamic shaker, instrumented hammer. Methods to restrain the structure: rigid and elastic supports. Mounting of the exciter. Types of excitation: stationary (step sine, slow sine sweep) or transient (impulse, fast sine sweep). **Experimental modal analysis:** Identification of modal parameters in the frequency domain. Theoretical bases of Single Degree of Freedom (SDOF) methods: estimation of natural frequency from FRF plots (modulus, phase, real part, imaginary part, Nyquist plot). Damping estimate: half power points. Modal circle: natural frequency and damping factors estimate. Inverse plot. Extension to N degrees of freedom systems: the SDOF assumption. SDOF methods: peak amplitude, quadrature response, circle fit, line fit (Dobson). Low and high frequency residuals. MDOF methods: Non Linear Least Squares (NLLS); Rational Fraction Polynomials (RFP), etc. Comparison among mode shapes: modal assurance criterion (MAC). **Random processes:** Basic probability theory. Random variables and probability distributions. Expectations of functions of a random variable. Stochastic processes: ensemble averages. Stationarity. Correlation functions. Ergodicity: time averages. Power and cross spectral density. Wide band and narrow band processes: white noise. **Random vibrations:** Linear system response to random input. Single DoF systems: frequency response function estimation. Response to white noise. Coherence function: effect of measurement noise. Response of N-DoF systems to random inputs. Response of continuous systems to random inputs. **Waves:** Longitudinal and quasi-longitudinal waves. Bending waves: phase and group speed, energy relations. Wave motion on rods and beams of finite length: longitudinal natural vibrations, natural vibrations in bending, wave train closure principle. On successful completion of this module, the student should: - have profound **knowledge** and demonstrate **ability** to model and analyze both discrete and continuous vibrating systems; - demonstrate **abiliity** to design experimental tests in order to identify the dynamic properties of vibrating systems.
3	**Prerequisites and learning activities**	The student must comply with the admission requirements to the 2nd level Course in Mechanical Engineering
4	**Teaching methods and language**	Lectures and exercises. Language: Italian **Ref. Text books** Walter D'Ambrogio, ***Lecture notes*** (in Ialian) available to registered users at link http://www.didattica.univaq.it/moodle/course/view.php?id=4517 Rao, **Mechanical Vibrations**, Prentice-Hall, 2005.
5	**Assessment methods**	Written and oral exam.