

**WALTER D'AMBROGIO**

<p align="center"><b>Programme of “Meccanica delle Vibrazioni” “Mechanical Vibrations”</b></p>		
<p align="center"><b>Number of ECTS credits: 6 (workload is 150 hours; 1 credit = 25 hours)</b></p>		
<p><b>I0233, Compulsory</b></p>		
<p><b>2nd Cycle in MECHANICAL ENGINEERING (Energy track), 1<sup>st</sup> year , 1<sup>st</sup> semester</b></p>		
<p><b>Teacher: Prof. Walter D’Ambrogio</b></p>		
<b>1</b>	<b>Course objectives and Learning outcomes</b>	<p>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.</p>
<b>2</b>	<b>Dublin descriptors</b>	<p>Topics of the module include:</p> <p><b>Vibrations of single degree of freedom systems:</b> 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.</p> <p><b>Vibration of multiple degree of freedom systems:</b> 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.</p> <p><b>Vibration of continuous systems:</b> 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.</p> <p><b>Signal analysis:</b> 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</p>

		<p>smearing. Minimisation of leakage: time windowing.</p> <p><b>Modal testing:</b> 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).</p> <p><b>Experimental modal analysis:</b> 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).</p> <p>On successful completion of this module, the student should:</p> <ul style="list-style-type: none"> <li>- have profound <b>knowledge</b> and demonstrate <b>ability</b> to model and analyze both discrete and continuous vibrating systems;</li> <li>- demonstrate <b>ability</b> to design experimental tests in order to identify the dynamic properties of vibrating systems.</li> </ul>
3	<b>Prerequisites and learning activities</b>	The student must comply with the admission requirements to the 2 <sup>nd</sup> level Course in Mechanical Engineering
4	<b>Teaching methods and language</b>	<p>Lectures and exercises. Language: Italian</p> <p><b>Ref. Text books</b></p> <p>Walter D'Ambrogio, <i>Lecture notes</i> (in Italian) available to registered users at link <a href="http://www.didattica.univaq.it/moodle/course/view.php?id=4517">http://www.didattica.univaq.it/moodle/course/view.php?id=4517</a></p> <p>Rao, <b>Mechanical Vibrations</b>, Prentice-Hall, 2005.</p>
5	<b>Assessment methods</b>	Written and oral exam.