

TIME TABLE

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	September 5	September 6	September 7	September 8	September 9
9.00 - 9.45	Registration	Sinha	Rand	Fidlin	Sinha
9.45 - 10.30	Dohnal	Sinha	Rand	Fidlin	Sinha
11.00 - 11.45	Rand	Thomsen	Awrejcewicz	Thomsen	Dohnal
11.45 - 12.30	Rand	Thomsen	Awrejcewicz	Thomsen	Dohnal
14.00 - 14.45	Awrejcewicz	Fidlin	Sinha	Rand	
14.45 - 15.30	Awrejcewicz	Fidlin	Sinha	Rand	
16.00 - 16.45	Thomsen	Awrejcewicz	Fidlin	Dohnal	
16.45 - 17.30	Thomsen	Awrejcewicz	Fidlin	Dohnal	

ADMISSION AND ACCOMMODATION

The registration fee is of 575,00 Euro + VAT taxes*, where applicable (bank charges are not included).

The registration fee includes a complimentary bag, four fixed menu buffet lunches (Friday subject to numbers), hot beverages, downloadable lecture notes and wi-fi internet access.

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through our web site: <http://www.cism.it> or by post.

A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

Applicants may cancel their course registration and receive a full refund by notifying CISM Secretariat in writing (by email) no later than two weeks prior to the start of the course.

If cancellation occurs less than two weeks prior to the start of the course, a Euro 50,00 handling fee will be charged. Incorrect payments are subject to Euro 50,00 handling fee.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel or students' dormitories, if available.

Requests should be sent to CISM Secretariat by **July 5, 2016** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

Information about travel and accommodation is available on our web site, or can be mailed upon request.

Please note that the Centre will be closed for summer vacation the first three weeks in August.

* Italian VAT is 22%.

For further information please contact:

CISM
 Palazzo del Torso
 Piazza Garibaldi 18
 33100 Udine (Italy)
 tel. +39 0432 248511 (6 lines)
 fax +39 0432 248550
 e-mail: cism@cism.it



Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

ACADEMIC YEAR 2016
The Favre Session

TIME-PERIODIC SYSTEMS: THEORY AND APPLICATION

Advanced Professional Training
coordinated by

Fadi Dohnal
Ansaldo Energia
Switzerland

Richard Rand
Cornell University
USA

Udine September 5 - 9 2016

TIME-PERIODIC SYSTEMS: THEORY AND APPLICATION

This course provides a thorough introduction into basic and advanced concepts in applied mathematics, mechanics and engineering (civil, mechanical and electrical) on the analysis and design of time-periodic systems. A balance is provided between classic procedures, recent trends in the analysis and experimental observations of resonant and non-resonant behavior. A wide range of problems and their dynamic aspects are covered starting from simple linear differential equations, over small (perturbative) nonlinearities to strongly nonlinear systems including friction and contact, up to partial differential equations, delayed differential equations and large systems of differential equations. Special topics like high-frequency parametric excitation, quasi-periodic excitation, parametric excitation in gyroscopic systems and efficient analysis of complex structures are discussed. All main dynamic effects are substantiated by experimental observations at lab scale as well as in real applications. Standard techniques in the context of parametric excitation are outlined like the Floquet theory, the method of averaging, the method of multiple scales and the complexification method which enable the (semi-) analytical description of stability boundaries

in the system parameter space. Armed with these tools, analytical and numerical investigations of both multibody and continuous mechanical/mechatronic systems under parametric and external periodic excitations are discussed. Analytical studies are employed to detect and analyze stationary and non-stationary resonances. Numerical and experimental investigations are carried out for analyzing regular, chaotic, bifurcation and synchronization phenomena. The not well-known coexistence phenomenon and disappearance of resonance tongues is discussed in detail (Ince's generalization of Mathieu's equation) and the effects of quasi-periodic forcing and of time delay on the system dynamics are outlined. One major point for real applications is the ability of a specific procedure to analyze (non-)linear, time-periodic systems consisting of large number of degrees of freedom. The classic Floquet method cannot be applied to this kind of system due to the high sensitivity of the results on numerical round-off errors. The symbolic calculation of the Lyapunov transformation matrix based on the Chebyshev polynomials is introduced which enables a transformation of the original time-periodic problem to a

time-invariant problem and down-scale the system to the relevant variables. A symbolic control technique for Floquet multiplier placement for linear time-periodic systems and bifurcation control and feedback linearization techniques for nonlinear time-periodic systems are presented. Reduction procedures of PDEs to ODEs are discussed with an emphasis on the reliability and validity of the obtained results. Advantages of construction of charts of vibration types and application of the Morlet wavelets and Lyapunov exponents are illustrated. Another branch of this course covers linear and nonlinear effects of high-frequency (HF) time-periodic excitation which lead to the main non-trivial effects like stiffening, biasing and smoothing and highlights their practical importance. Generalized results for nonlinear systems with rapid time-harmonic excitation are derived and extended to nonlinear discrete mechanical systems and linear continuous systems. The connection to practical examples is given by using HF excitation to quench friction-induced vibrations and resolving the famous Chelomei's pendulum. The dynamic behaviour of discontinuous time-periodic systems covering different types of discontinuities like mechanical

slip, stop and friction is discussed. Asymptotic methods are generalized for non-smooth and discontinuous systems. Friction can be the energy source for exciting vibrations but can also be used for quenching vibrations excited by periodic forces. Methods for analysis of oscillations in strongly damped systems are derived and these tools are then exploited to design a sequential friction-spring for quenching resonance or understand the resonance in systems with inelastic collisions. The positive effect of a parametric combination resonance, the so-called parametric anti-resonance is discussed analytically and numerically for simple 2DOF systems as well as MDOF systems. The conditions under which a parametric excitation becomes a parametric anti-resonance are derived in detail. These conditions allow interpreting the attenuation effect as a modal interaction due to time-periodicity. The major findings are verified experimentally and future application fields are outlined. This course offers a condensed view on time-periodic systems, their analytical and numerical analysis and avoidance or exploitation of parametric resonances. The underlying theory is explained and applied to simple and real-life engineering examples.

INVITED LECTURERS

Jan Awrejcewicz - Lodz University of Technology, Poland
6 lectures on: Multibody and continuous systems under parametric and external periodic excitations; nonlinear dynamical phenomena; plane triple pendulum and spatial double pendulum with Cardan joints; numerical and experimental investigations of regular, chaotic, bifurcation and synchronization phenomena; coupled beams and plates governed by non-linear PDEs; reduction of PDEs to ODEs; constructing charts of vibration types; Morlet wavelets and Lyapunov exponents.

Fadi Dohnal - Ansaldo Energia, Switzerland
5 lectures on: Local stability analysis of gyroscopic systems; parametric anti-resonance of a 2DOF system; analytical approximation of stability; extension to MDOF systems; equivalent damping and modal energy transfer in linear systems; interaction between parametric excitation and self-excitation; examples: passage through critical speeds; active magnetic bearings, stability in fluid-film bearings, chatter during milling process.

Alexander Fidlin - Karlsruhe Institut für Technologie, Germany
6 lectures on: Discontinuities in dynamic systems, asymptotic methods generalized for non-smooth and discontinuous systems; friction for quenching vibrations, systems with almost elastic collisions (unfolding transformations); system with a one-sided stop, backlash, oscillations in strongly damped systems; averaging in strongly damped systems; examples: state feedback control, Jeffcott rotor passing through resonance, using sequential friction-spring for quenching resonance.

Richard Rand - Cornell University, USA
6 lectures on: Examples on parametric excitation (Mathieu's equation): vibratory fruit removal, frequency entrainment in a micromechanical oscillator (MEMS), particle in the plane (autoparametric excitation); PDE version of Mathieu's equation (Faraday's crispations); Ince's generalization of Mathieu's equation (coexistence phenomenon and disappearance of resonance tongues); dynamic effects of quasi-periodic forcing and time delay.

Subhash Sinha - Auburn University, USA
6 lectures on: Analysis and control of parametrically excited nonlinear dynamical systems; Chebyshev polynomials approximating Lyapunov-Floquet transformation; bifurcation analyses via time-dependent center manifold reduction; bifurcation control and feedback linearization; controller design and order reduction for large-scale nonlinear systems; examples: rotorcraft blades in forward flight, flexible slider crank mechanism, control of chaotic systems to periodic orbits

Jon Juel Thomsen - Technical University of Denmark, Denmark
6 lectures on: Non-trivial effects of high-frequency vibrations: stiffening - biasing - smoothing; nonlinear single-DOF systems with high-frequency time-harmonic excitation; separation of motions, and comparison with alternative methods; generalized analysis and effects for nonlinear discrete mechanical systems, and for linear continuous systems; quenching friction-induced vibrations; Chelomei's pendulum - resolving a paradox; stiffening of flexible strings.

PRELIMINARY SUGGESTED READINGS

J. Awrejcewicz, Ordinary Differential Equations and Mechanical Systems, Springer, 2014.

J.J. Thomsen, Vibrations and Stability: Advanced Theory, Analysis, and Tools, Springer, 2003.

S. Sinha, A. Dávid, Bifurcation Analysis of Nonlinear Dynamic Systems with Time-Periodic Coefficients in Chaos and Bifurcation of Complex Systems, Eds. J.-Q. Sun and A.C.J. Luo, Elsevier Publications, 2006, pp. 279 – 338

R. Rand, Lecture notes on Nonlinear Vibrations, <http://www.math.cornell.edu/~rand/randdocs/nlvi-be52.pdf>.

F. Dohnal, Parametric anti-resonance: theory, experiment and

interpretation, Habilitation Thesis, TU Darmstadt, 2012.

A. Fidlin, Nonlinear Oscillations in Mechanical Engineering, Springer, 2006.

LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site, instructions will be sent to accepted participants.

**TIME-PERIODIC SYSTEMS:
THEORY AND APPLICATION**

Udine, September 5 - 9, 2016

Application Form

(Please print or type)

Surname _____

Name _____

Affiliation _____

Address _____

E-mail _____

Phone _____ Fax _____

Method of payment upon receipt of confirmation (Please check the box)

The fee is 575,00 Euro + 22% Italian VAT taxes, where applicable (bank charges are not included).

I shall send a check of Euro _____

Payment will be made to CISM - Bank Account No. 094570210900,
VENETO BANCA - Udine (CAB 12300 - ABI 05035 - SWIFT/BIC
VEBHIT2M - IBAN CODE IT46 N 05035 12300 09457 0210900).
Copy of the receipt should be sent to the secretariat

I shall pay at the registration counter with check or VISA Credit Card
(Mastercard/Eurocard, Visa, CartaSi)

**IMPORTANT: CISM is obliged to present an invoice for the above sum.
Please indicate to whom the invoice should be addressed.**

Name _____

Address _____

C.F.* _____

VAT/IVA* No _____

(* Only for EU residents or foreigners with a permanent business activity in Italy.

Only for Italian Public Companies

I ask for IVA exemption (ex law n. 537/1993 - art. 14 comma 10).

Privacy policy: I understand that data received via this form will be used only to provide information about CISM and its activities, within the limits set by the Italian legislative decree no. 196/2003 and subsequent amendments.

Complete information on CISM's privacy policy is available at www.cism.it.

I have read the "Admission and Accommodation" terms and conditions and agree.

Date _____ Signature _____