Applied Dynamics

José Antunes

The activities at Applied Dynamics Laboratory (ADL) are devoted to research in nuclear engineering, with an emphasis on the vibratory and acoustic behaviour of mechanical components. Our group started in 1986, with the following objectives: (1) Develop theoretical methods, computer tools and experimental techniques, to solve structural problems in nuclear power station components; (2) Use this state-of-the-art know-how, in order to solve structural problems arising in Portuguese power plants and other industrial facilities.

The first objective has been pursued through extensive international collaboration with our main scientific partner - the French Commissariat à l'Energie Atomique (CEA) / Département de Mécanique et Technologie (DMT). More than one decade of fruitful collaboration is attested by a significant number of published results. Important problems have been solved, such as nonlinear vibrations in steam-generators, flow-induced vibrations of nuclear fuel and stability problems in rotating machinery. Furthermore, new identification techniques have been developed and applied with success to nonlinear dynamical systems.

The second objective has been pursued by starting in 1990 a series of projects with (and for) the Portuguese power supplier Electricidade de Portugal / Companhia Portuguesa de Produção de Electricidade (EDP/CPPE), stemming from actual structural problems in power plants (Sines, Setúbal): These projects enabled us to model and solve vibratory problems arising in rotating machinery, vibro-acoustical problems in boilers and heat-exchangers, as well as structural identification problems. Several computer codes have been developed in connection with these projects.

In recent years we also developed research projects of more fundamental nature, mainly funded through the Portuguese Science Foundation (FCT) research programmes. These projects have been developed in partnership with several Portuguese institutions (Faculdade de Ciências de Lisboa, Instituto Politécnico do Porto, Instituto Politécnico de Setúbal, Instituto Superior Técnico, Universidade Nova de Lisboa), as well as the Université de Paris, Trinity College Dublin and Southampton University. This work, developed in the context of fundamental physics – in particular addressing problems in music acoustics, optimization and structural geology – is centred in modelling nonlinear dynamics and flow-structure phenomena. The methods developed transcend the context of these projects and may be adapted to solve several aspects of industrial problems.

The Applied Dynamics team is mainly concerned with the following scientific fields: structural dynamics, flow-induced vibrations, nonlinear dynamics, vibro-acoustics, experimental methods, signal processing, system identification, structural and acoustical optimization. As a spin-off from our research activities, teaching has been actively pursued on structural dynamics and acoustics - ranging from university level courses in Portugal (Coimbra, Lisbon) to several post-graduation short courses abroad (Paris, Dublin, Cargèse). Also, student and post-doc training, as well as several university thesis (MSc and PhD) have been successfully supervised, for both Portuguese and foreign students. An extensive book on fluid-structure dynamics and acoustics, co-authored by two researchers from CEA and ITN/ADL was internationally published during 2006 and another volume on flow-induced vibrations is currently under completion, to be released in 2009.

Among the above-mentioned scientific fields one should stress those features which give this small group a distinct profile from others working in structural dynamics in Portugal. Those features are: (1) a proven expertise and output in flow-excited systems and nonlinear vibrations; (2) a complementary theoretical/experimental approach for every problem.

Most of the research projects pursued at ADL have been based on both industry and academic research contracts. Research activities at ADL were internationally recognized by two prizes from the American Association of Mechanical Engineers (ASME).

In 2008, the Applied Dynamics group was blessed by welcoming a new researcher as permanent staff.

Research Team

Researchers

J. ANTUNES, Princ.
V. DEBUT, Aux. (contract since Feb.)

Students

O. INÁCIO (25%) Ph.D. Inv. Professor

Collaborators

L. HENRIQUE (10%), Ph.D., Adj. Professor , IPP Porto

Optimization of multimodal acoustic control resonators

J. Antunes, F. Axisa, V. Debut,O. Inácio[1]

Objectives

This project aims at the development of optimized resonating devices, for passive control of the frequency-dependent amplitude responses of the main acoustical systems to which they are attached. Achievement of this objective is connected with the development of analytical and numerical techniques for modeling and optimization of the resonators shape and location.

Results

The significance of this project lays in the fact that the dynamical behavior of many components in industrial plants and acoustic volumes can benefit from resonating auxiliary resonating devices, in order to avoid the effects of over-enhanced resonances. The number of controlled acoustic modes depends on the central frequency and damping of resonators, as well as on the modal density of the controlled system within the resonators frequency range. The original and powerful idea of this project is to improve the efficiency of such devices by – instead of using basic single degree of freedom Helmholtz resonators – develop shape-optimized and optimally located multimodal resonators, in order to cope with a large number of intrusive modes of the main system.

Results obtained in 2008 built on the previous development of a modal-based sub-structure theoretical approach to compute the coupled acoustical modes of volumes fitted with several multi-mode resonators (Figure 1). The theoretical model was further extended to include viscous boundary layer absorption effects at the acoustical volume/resonator interfaces. Such approach proved to be computationally very efficient, being therefore well suited for optimization purposes. Numerical results obtained showed the feasibility of this multimodal coupled resonator concept.

Most recent developments concern the resonators optimization, performed by iteratively adapting their shape and location in order to minimize a target error-measure, within imposed physical and/or geometrical constraints. As a specific illustrative application, using a global optimization technique – simulated annealing – we optimized two auxiliary resonators in order to level, within a given frequency range (20~100Hz), the acoustical frequency response function between a loudspeaker and a listening location in a given control room (Figures 2 and 3).

Such problem encapsulates most of the difficulties encountered in other fields, and we obtained truly representative results for the optimized complex acoustical problem. The results obtained so far suggest that very significant response improvements can be achieved, see Figure 2. This work highlights the potential of the proposed corrective methodology.

Published work

O. Inácio, J. Antunes, Shape-optimization of several multi-modal resonators accounting for room-resonator acoustical coupling (2008), *Acoustics* 2008, 29 June – 4 July 2008, Paris, France, abstract in *Journal of the Acoustical Society of America*, Vol. 123, p. 2983.

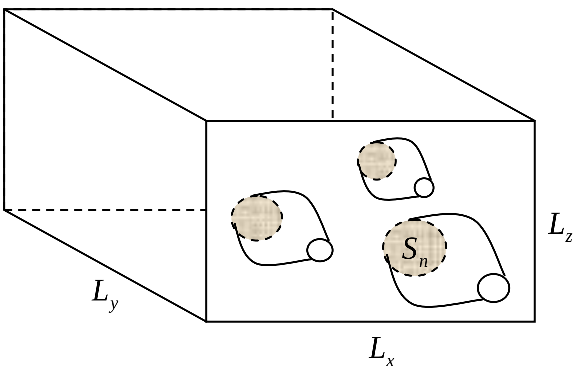

Figure 1: Room fitted with multi-mode resonators.

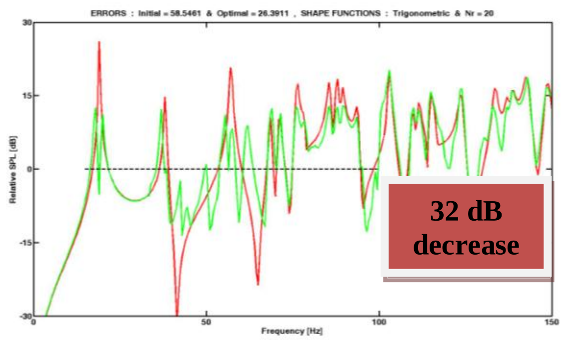

Figure 2: FRFs of the original (red) and corrected (green) room using optimal resonators.

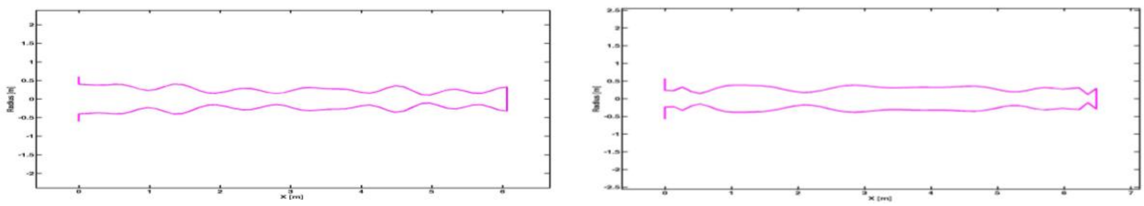

Figure 3: Examples of optimal resonators, with shapes described respectively using sets of trigonometric functions and of Chebyshev polynomials.

[1] Inst. Politécnico do Porto, ESMAE, Lab. of Music Acoustics

Flow-induced vibrations of tubular nuclear components

J. Antunes, X. Delaun[1], P. Piteau[1],L. Borsoi[1]

Flow turbulence excitation is a common source of structural vibrations, leading to fatigue failures and wear. For nuclear facilities, such problem must be addressed with particular care, for obvious safety reasons. At ITN/ADL, under contract with CEA-Saclay, we gained significant expertise in this area. This project, now third year, is aimed at the development of up-to-date software to compute the flow-induced vibrations of nuclear components such as fuel rods or steam-generator tubes. Nonlinear vibro-impact phenomena between the tubes and their supports are incorporated in the nonlinear time-domain computational models. During 2008 a new version of our computer program was developed, incorporating a "direct" method for the time-domain generation of partially space-correlated turbulence excitations. Such technique is based on a Proper Orthogonal Decomposition (POD) of the cross-spectral complex matrix of the random field, followed by inverse FFTs of the frequency-domain signals. This excitation method proved well suited for both axial and transverse flows. We are currently comparing the linear and nonlinear system responses obtained using this turbulence simulation technique with those stemming from an original simplified method developed in 2007.

[1] Commissariat à l'Energie Atomique, Lab. of Dynamical Studies, Saclay, France

Modeling and reduction of aeroacoustic noise in flow-conveying systems

M. Moreira[1], V. Debut, J. Antunes, H. Pina[2], J. Paulino[3]

The interaction between a gaseous flow and the tube banks of heat exchangers often leads to self-excitation of acoustic resonances which can seriously affect the system integrity. Similar problems also arise in pipe-systems. In spite of the industry concern, the physical mechanisms of sound excitation are still far from understood and current stability criteria are not trustful. This three years project, funded by a FCT grant, aims at increasing our understanding of the relevant physical mechanisms of aero-acoustic instabilities, and also developing techniques for optimizing the acoustical devices used to inhibit them. Following our theoretical work previously developed, we performed new wind tunnel experiments to validate a simplified numerical model of the vortex-excited acoustic field, coupled with global optimization methods for the optimal configuration of acoustical baffles. Concerning a closely related problem of industrial interest, the acoustic self-excitation of corrugated pipes under axial flow, a conceptual phenomenological model was developed to reproduce the qualitative trends observed in experiments with corrugated pipes. Such model involves coupling an acoustic pipe with a line of self-excited oscillators which stand for the corrugations vortex excitation. This model was explored through extensive time-domain simulations and complex modal computations.

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[2] Instituto Superior Técnico de Lisboa, Department of Mechanical Engineering
[3] Instituto Superior de Engenharia de Lisboa, Department of Mechanical Engineering

Vibro-acoustical modelling of structures coupled with two-phase fluid mixtures

V. Debut, J. Antunes

Energy dissipation in bubbly mixtures is an important issue, as many industrial components operating in two-phase fluids are prone to flow-induced vibrations, nuclear steam generators for instance. Understanding such dissipative phenomena is required to avoid excessive vibrations, which depend on the mixture void fraction and flow regime. A significant increase of damping is observed in two-phase flow, however the nature of the dissipation mechanisms remains an open issue. As a step toward fundamental understanding, we performed preliminary experiments on a cylindrical shell filled with a bubbly liquid. Modal identification was achieved by implementing the Eigen-Realization Algorithm (ERA). These tests demonstrated the strong attenuation due to two-phase damping. A theoretical model involving piston oscillators coupled by a bubbly liquid was developed, using a fourth-order linearized model for the wave propagation in two-phase mixtures. The set of modal ODEs obtained after modal projection provided numerical time-domain simulations, as well as frequency-domain computation of the coupled modes as a function of the mixture void fraction. Preliminary results show that our theoretical model encapsulates the qualitative trends of real systems.

Dynamical modelling of nonlinear vibratory and acoustical systems

J. Antunes, O. Inácio[1], M. Wright[2]

This research started some years ago as a FCT funded project, an international cooperative effort to develop theoretical methods and numerical techniques for dealing with strongly non-linear dynamical problems, such as involving impacts and friction phenomena. The main objective was the development of modeling techniques for nonlinear multi-modal structures. In previous years we developed efficient numerical techniques to predict the nonlinear dynamics and interaction forces of friction self-excited systems, including strings, bars and shells, as well as complex coupled sub-systems. During 2008 we have extended our computational methods in order to model the controlling effect on self-excited vibratory responses of secondary coupled oscillators. The theoretical results thus obtained were validated by experiments. A PhD thesis was presented at Southampton University, examination being scheduled for February 2009.

[1] Instituto Politécnico do Porto, ESMAE, Laboratory of Music Acoustics
[2] University of Southampton, Institute of Sound and Vibration Research, UK