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).

A new researcher joined the permanent staff of the Applied Dynamics group in 2008, being involved since in most of our research activities.

Research Team

Researchers

J. ANTUNES, Princ.
V. DEBUT, Assist. (Contract)

Students

O. INÁCIO (20%), PhD, Adj. Prof., IPP Porto

Collaborators

L. HENRIQUE (10%), PhD, Adj. Prof., IPP Porto
M. MOREIRA (20%), PhD, Adj. Prof., IPS Setúbal
M. PAULINO (10%), MSc, Inv. Prof., IPL Lisboa

Modelling and remote identification of dynamical impact/friction interaction forces

J. Antunes, V. Debut, X. Delaune[1], P. Piteau[1], O. Inácio[2]

Objectives

Many mechanical components of industrial significance are subjected to impact/friction local forces which are extremely nonlinear in nature. For achieving realistic numerical computations of these systems, a good understanding of the interaction phenomena is of great importance. The direct measurement of such forces is often difficult, due to the lack of room for instrumentation or the aggressive environmental conditions (temperature, radiation). The objective of this project is the *development of modal methods for the remote identification of local contact forces*. This work, performed in close collaboration with CEA/Saclay (France), aims a better knowledge of the local contact/friction laws, in order to refine our modelling techniques and physical understanding.

Results

In this project we focus on two specific problems: (a) A vibro-impacting beam, fairly representative of nuclear steam-generator tubes; (b) A bowed string subjected to self-excited motions. These two problems display complementary features of interest. We have theoretically addressed the vibro-impact modelling and identification problems (experiments are being prepared at CEA/Saclay), while making a full theoretical and experimental study of the bowed string at ADL. Using numerically simulated dynamical responses, we developed an identification technique, based on inverse methods, which can cope with the flow turbulence perturbation (Figure 1). Our modal identification approach also enabled the remote identification of bow/string interface forces, as well as the self-excited motion at the contact location, from the dynamical reactions measured at the string pinned ends (Figure 2). Effectiveness of the identification method has already been confirmed by post-processing numerical simulations. Furthermore, using the test rig and identification software developed at ADL, the first experimental friction force identifications have been already obtained, with very encouraging results. Various aspects of these were published at three international conferences and two international journal papers. Several more have been already abstracted to be presented at conferences in 2010.

Publications

V. Debut, X. Delaune, J. Antunes, "Identification of nonlinear interaction forces acting on continuous systems using remote measurements of the vibratory responses", *International Journal of Mechanical Science* (in print).

X. Delaune, J. Antunes, V. Debut, P. Piteau, L. Borsoi, "Modal techniques for remote identification of non-linear reactions at gap-supported tubes under turbulent excitation", *ASME Journal of Pressure Vessel Technology* (in print).

V. Debut, C. Bersac, J. Antunes, "Identification of the dynamical bow/string friction interaction force from vibratory measurements using inverse methods". *Proceedings of the 16th International Congress on Sound and Vibration (ICSV09)*, 5-9 July 2009, Krakow, Poland.

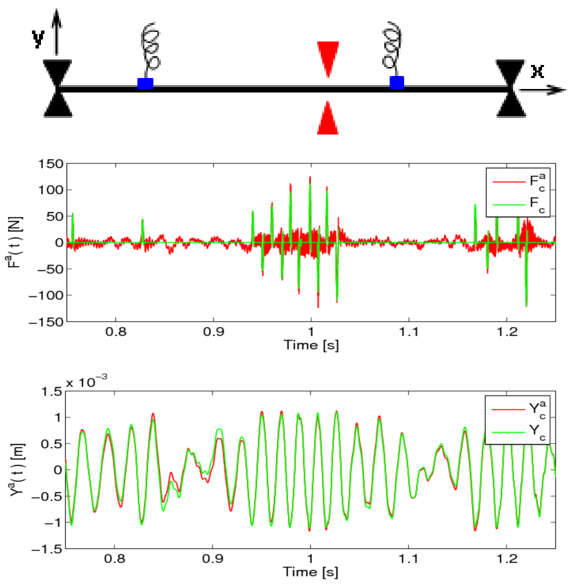

Fig.1 Remote identifications on a vibro-impacting beam: Original (green) and identified (red) impact force and beam motion at the gap-support location.

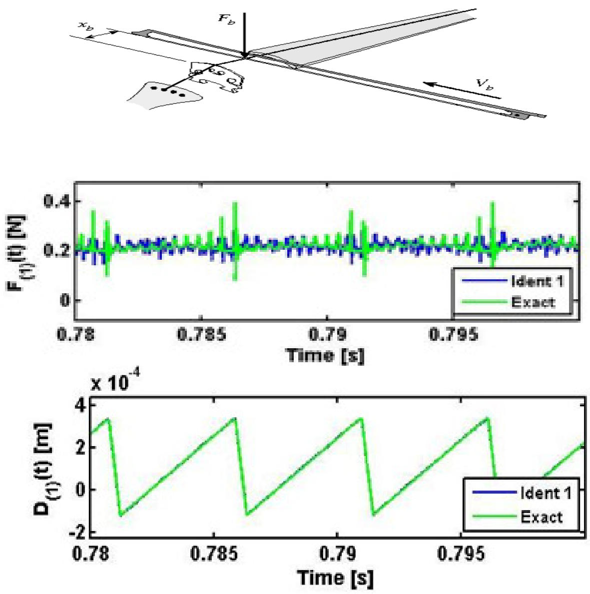

Fig.2 Remote identifications on a bowed string: Original (green) and identified (blue) friction force and string motion at the bow excitation location.

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Flow-induced vibrations of tubular nuclear components

J. Antunes, P. Piteau[1], X. Delaune[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 (contract VITAMINE-3), we gained significant expertise in this area. This project, now in its fourth year, is aimed at the development of up-to-date software to compute the turbulence-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 2009, we compared extensively the original method for generating time-domain turbulence excitations, which developed at ADL, with a "direct" method based on the Proper Orthogonal Decomposition (POD) of the cross-spectral complex matrix of the random field. The results obtained are satisfying and of similar quality, however our original technique is computationally more efficient. On the other hand, under a different contract with CEA (contract TGVsurVITAMINE), we developed a computer program for predicting the vibro-impact responses of tubes subjected to the flow fluidelastic forces. The results obtained are currently being validated by experiments performed at CEA-Saclay.

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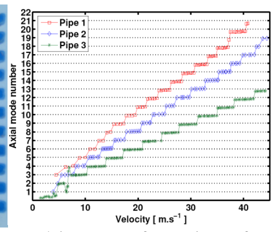
Modeling and reduction of aeroacoustic noise in flow-conveying systems

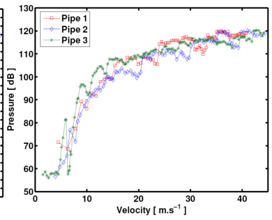
V. Debut, J. Antunes, C. Meskell[1], M. Moreira[2], J. Paulino[3]

In the context of aerodynamic noise generation, corrugated pipes emit clear and loud lock-in tones, when air flows through them at sufficiently high velocities, due to coupling between vortex shedding triggered by the flow and the acoustical field. Such flow-excited acoustic phenomenon is encountered in a large variety of applications and can induce both environmental noise problems and significant structural vibrations. In recent years we developed a conceptual phenomenological modelling approach to reproduce the qualitative trends observed with experiments in corrugated pipes (Debut & Antunes, 2007), which was explored through extensive numerical time-domain simulations (Debut & Antunes, 2008). During 2009 the effect of small irregularities on the aero-acoustic source characteristics was investigated numerically, showing that dispersion in several of the oscillator parameters can change qualitatively the dynamical behaviour of the nonlinear model. The work on this very difficult problem is still in progress, focusing on aspects connected with the nature of the aeroacoustic sources. To proceed further, a preliminary analysis of the system using Computational Fluid Dynamics (CFD) was started in collaboration with the Department of Mechanical engineering of the Trinity College in Dublin (TCD), which certainly will prove fruitful in the near future.

Two samples of tested corrugated pipes.



Lock-in resonance frequencies as a function of the flow velocity



Acoustical pressure responses as a function of the flow velocity

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[2] Inst. Politécnico de Setúbal, Esc. Sup. de Tec., Dept. of Mathematics;[3] Inst. Sup.de Engenharia de Lisboa, Dept. of Mechanical Engineering

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

V. Debut, J. Antunes

The nature of energy dissipation mechanisms in bubbly mixtures is an important topic, since many industrial components operating in two-phase flow are prone to flow-induced vibrations (heat exchangers and nuclear steam generators, for instance). To avoid excessive vibrations requires a precise understanding of damping mechanisms. A significant increase of damping is observed in two-phase fluid and, as stated by Pettigrew (1997), "the true nature of energy dissipation mechanisms in two-phase mixtures is still unknown". The theoretical and experimental project pursued at LDA is intended to bring some light to this problem, by focusing on the specific, and hopefully simpler, case of bubbly stagnant mixtures. Experiments were previously performed on a cylindrical shell filled with a bubbly liquid. This demonstrated qualitatively the strong attenuation due to the "two-phase damping" phenomenon. At the theoretical level, a simple model involving two piston oscillators coupled by a pipe filled with a bubbly liquid was proposed, based on a homogeneous model of bubbly liquid in the form of an extended wave equation (Debut & Antunes, 2008). During 2009, we refined our theoretical formulation using a discrete representation of the bubble population dynamics, coupled with a wave equation for the surrounding liquid. Then, a set of modal ODEs obtained after modal projection provided both numerical time-domain simulations and computation of the coupled modes. Such discrete model highlighted interesting properties of the bubbly liquid damping, in relation with the collective motions of the bubbles or, as an opposed scenario, caused by localized high amplitude bubble breathing. As a result of this work, one international conference paper was published in 2009. Quite recently, a preliminary effort on a more realistic two-dimensional model of the bubbly fluid and shell system was started.