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.

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, Vincent Debut, 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, Aux. (Contrat)

Collaborators

O. INÁCIO (15%), PhD, Adj. Professor (1)
L. HENRIQUE (10%), PhD, Adj. Professor (1)
M. MOREIRA (20%), PhD, Adj. Professor (2)
M. PAULINO (10%), MSc, Inv. Professor (3)
(1) IPP, Porto
(2) IPS, Setúbal
(3) IPL, Lisboa

Flow-induced vibrations of tubular nuclear components with vibro-impacting at support clearances

J. Antunes[1], P. Piteau[2], X. Delaune[2], V. Debut[1], L. Borsoi[2]

Objectives

In nuclear facilities, flow turbulence excitations and fluid-elastic phenomena may induce structural vibrations or instabilities, leading to fatigue failures and wear, which must be addressed with particular care for safety reasons. At ITN/ADL, in a long-term close collaboration with CEA-Saclay (contract TGV-ICE), we gained significant expertise in these areas. This project is aimed at the development at ITN/LDA of up-to-date software to compute turbulence-induced and fluid-elastically unstable vibrations of nuclear components, such as fuel rods or steam-generator tubes, with an experimental validation of the computational methods at the flow test-loop of CEA-Saclay. These experiments were performed by our French colleagues.

Results

The experimental setup shown in Figure 1 was used as a representative tube steam-generator bundle geometry for both the theoretical and the experimental work. A flexible tube, within a rigid bundle, was excited by the flow for two different configurations: (a) A linear system consisting on the clamped-free vibrating tube; (b) A vibro-impact nonlinear system, after two rigid clearance stops were positioned near the free-end of the tube. Configuration (a) was used for extracting the flow turbulence excitation spectrum from the linear tube responses, as well as the fluid-elastic coupling coeficients $C_f(V_R)$ and $K_f(V_R)$, as a function of the dimensionless flow velocity V_R. Then, the identified turbulence and flow-coupling data were used to predict the nonlinear tube responses after the clearance supports were installed.

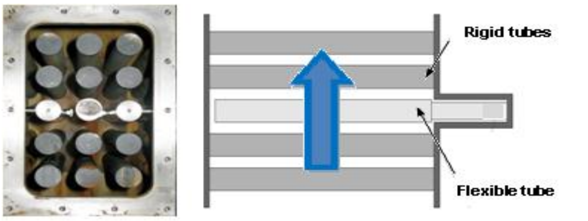

Fig.1 Test rig developed at CEA-Saclay for experimental validation of the software developed at ITN/ADL.

Figure 2 illustrates one such computation, showing the impulsive impact forces and the gap-limited tube vibrating motion, as well as an estimate of the "instantaneous" tube response frequency $f_r(t)$, which was needed for computing the reduced velocity V_R and hence the coupling coefficients. As illustrated in Figure 3, the computational and experimental results obtained constitute an overall validation of our approach to deal with gap-supported tubes subjected to fluid-elastic forces and turbulence. The main point successfully addressed was to assert the validity of computing the nonlinear and unsteady vibro-impact responses of fluid-elastically unstable tubes, knowing that the fluid-elastic coupling coefficients are provided by tests performed under steady oscillatory conditions.

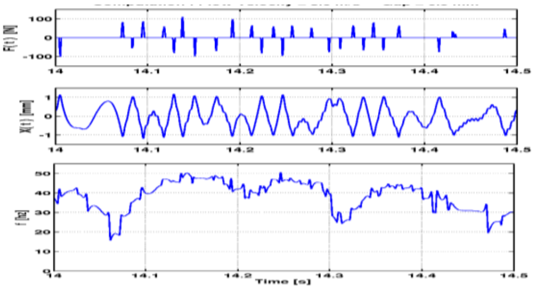

Fig. 2 Computations of a vibro-impact regime, showing the impact force and tube displacement at the gap-support, as well as the "instantaneous" response frequency.

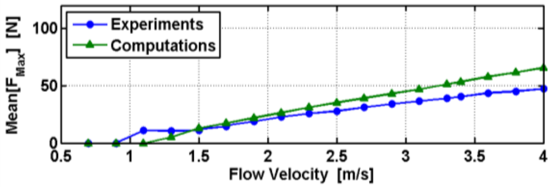

Fig. 3 Comparison between computed and experimental mean impact forces at the gap-support, for a series of tests.

Results connected with this work were already published at two international conferences and two journal papers, with a third journal paper in print.

Publications

P. Piteau, X. Delaune, J. Antunes, L. Borsoi, "Vibro-impact experiments and computations of a gap-supported tube subjected to single-phase fluid-elastic coupling forces", Paper FEDSM-ICNMM2010-30071, *Proc. 7th Int. Symp. Fluid-Structure Interaction, Flow-Sound Interaction, Flow-Induced Vibration & Noise*, 1-5 August 2010, Montreal, Canada.

X. Delaune, P. Piteau, V. Debut, J. Antunes, "Experimental validation of inverse techniques for the remote identification of impact forces in gap-supported systems subjected to local and flow turbulence excitations", Paper PVP2010-26133, *Proc. ASME 2010 Pressure Vessels & Piping Conference*, 18-22 July 2010, Bellevue, USA.

V. Debut, X. Delaune, J. Antunes, "Identification of nonlinear interaction forces acting on continuous systems using remote measurements of the vibratory responses", *Int. Journal of Mechanical Science*, Vol. 52, pp. 1419-1436 (2010).

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*, Vol. 132, Paper 031801.

X. Delaune, P. Piteau, V. Debut, J. Antunes, "Experimental validation of inverse techniques for the remote identification of impact forces in gap-supported systems subjected to local and flow turbulence excitations", *ASME Journal of Pressure Vessel Technology* (in print).

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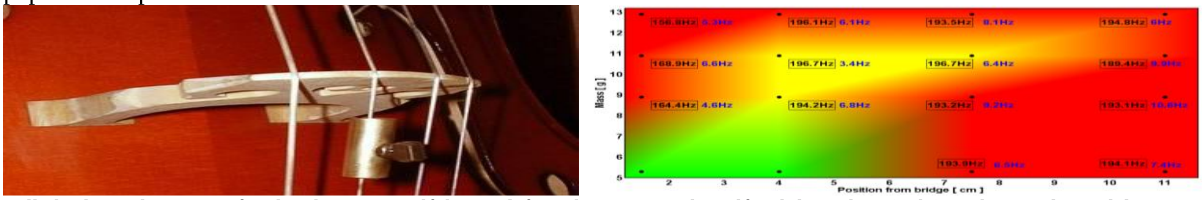
String/body coupling in string instruments

V. Debut[1], J. Antunes[1], O. Inácio[2], P. Serrão[3], A. Ribeiro[3]

In the context of the FCT project PTDC/FIS/103306/2008, we pursued our study on the coupled body/string dynamics of bowed instruments. A common annoying phenomenon which arises is the so-called "wolf note", which is a warbling sound stemming from a severe interaction between the string and the body motions, coupled through the instrument bridge. We addressed the dynamical behavior of the string/body/wolf-eliminator coupled system, both theoretically and through experiments performed on a XIXth century cello. This study contributed to clarify the functioning of this anti-wolf device and provides guidelines for an effective use. Two conference papers were published as a result of this work.



Cello bridge and G2 string fitted with an anti-wolf device (left) and experimental "wolf-stability" chart (right), with normal sound domains in green, easily played wolfs in red and rarely sounding wolfs in yellow.

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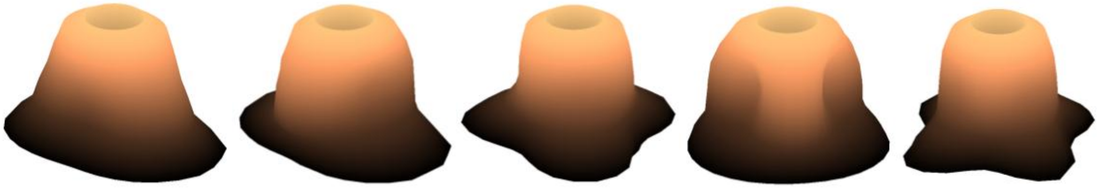
[3] Instituto Superior Técnico, Lisbon

Dynamical analysis and tuning of carillon bells

J. Antunes[1], V. Debut[1], O. Inácio[2], J. Soeiro de Carvalho[3]

In the context of the FCT project PTDC/EAT-MMU/104255/2008, we have started a three-year project dealing on the physical and musicological aspects of the historical Mafra carillons, from the XVIIth century. As a first step on the work for asserting the current state of tuning (or mistuning) of the carillons, laboratory experiments were performed on a contemporary bell, in order to establish adequate procedures and techniques for the modal identification on a large number of bells. Following this study, the identification field-work will take place early in 2011. Then, the main task for ITN in this project - the development of optimal tuning procedures - will follow.



Experimentally identified modes of the laboratory bell: modal frequencies ranging from 643 Hz to 2675 Hz.

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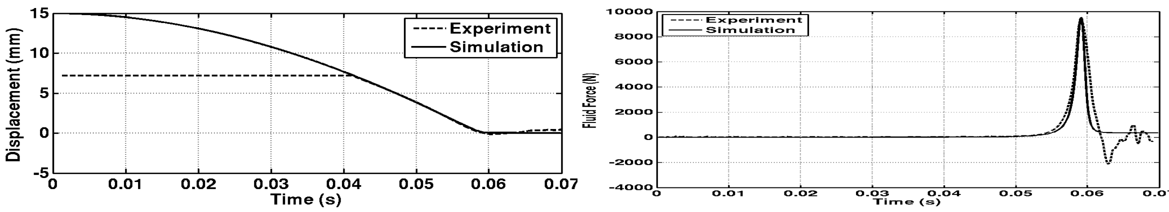
Nonlinear squeeze-film vibrations of planar structural components

J. Antunes[1], P. Piteau[2]

Squeeze film dynamical effects are relevant in many industrial components, including bearings and seals, as well as when dealing with the seismic excitation of spent nuclear fuel racks. The significant nonlinearity of the squeeze-film forces prevents the use of linearised flow models. In this project a simplified analytical model, based on gap-averaged Navier-Stokes equations and incorporating all relevant inertial and dissipative terms, was developed. The dependence of the flow friction coefficient on the local flow velocity is explicitly accounted for, so that it can be applied to laminar, turbulent and mixed flows. Following these theoretical developments, extensive experiments were performed at CEA/Saclay, on a test rig consisting on a gravity-driven instrumented rectangular plate colliding with a planar surface. The theoretical results were compared with the experimental measurements, with success. A conference paper and one journal paper were published as a result of this work.



Comparison between the theoretical and experimental motion (left) and squeeze-film fluid force (right) for a dropping plate (experimental displacement clipped beyond 7 mm).

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