Applied Dynamics

Introduction

The research activities of the "Applied Dynamics Laboratory" (*ADL*) started in 1986, with the following main objectives:

- Develop *theoretical methods*, *computer tools* and *experimental techniques*, to solve structural problems in *nuclear power station* components;
- 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 were solved, such as nonlinear vibrations in steam-generators, flow-induced vibrations of nuclear fuel, as well as stability problems in rotating machinery. The second objective has been pursued by starting in 1990 a series of projects with (and for) the portuguese power supplier "Electricidade de Portugal (EDP)", 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 heat-exchangers, as well as structural identification problems.

From the previous statements, one may conclude that the *ADL* is mainly concerned with the following scientific fields: *structural dynamics, flow-induced vibrations, nonlinear dynamics, vibro-acoustics, experimental methods, signal processing and system identification.* As a spin-off from the research activities at *ADL*, teaching has been actively pursued on *structural dynamics* and *acoustics* — ranging from university level curses in Portugal (Coimbra, Lisbon) to post-graduation short curses abroad (Paris, Dublin). Also, student training and university thesis (Graduation, MSc and PhD) have been successfully supervised at *ADL*, for both portuguese and foreign students.

The Applied Dynamics Laboratory is equipped for finite element computations, applied to static and dynamic analysis of complex structures. Such computations are performed using CASTEM 2000, a general purpose computer code developed by our partners from CEA (France). More advanced analysis are performed with specific computational tools, developed at *ADL*, for instance to study nonlinear dynamic phenomena or flow-structure interaction problems. The *ADL* has a large experience in experimental dynamics, and is well equipped for data acquisition and signal processing. Such facilities have been applied for the experimental analysis of nonlinear structures and flow-excited systems, as well as for identification problems. The test rigs are designed at *ADL* and developed at ITN workshop facilities.

During 1997, several research projects were pursued and/or completed — namely, “Rotor-flow interaction”, “Remote impact identification”, “Vibration problems in power generators”, ”Experimental modal analysis” and “Nonlinear modeling and dynamics”. A new project was started, in the framework of a PhD thesis — “Identification and simulation of complex systems using stochastic optimization methods”. Most of these projects are entirely founded by external partners. Research results have been published in wide-audience journals and international meetings.

Research Team

Due to previous government restrictions, the size of permanent staff at *ADL* is severely sub-optimal. At the present time, only *one researcher* and *one technician* work permanently at *ADL*. As happened in previous years, the accomplishment of our goals for 1997 was only possible with the contribution of graduate and post-graduate students, as well as through international collaboration. Clearly, these very stressing working conditions must improve urgently. The research team in 1997 is next listed:

- Researchers: 1 (PhD)
- Research Students: 4(*)
- Technicians: 1

(*) These research students were financed using resources from *ADL* contract work.

Publications

Proceedings – 3

Reports – 6

10^3 PTE

Expenditure:	**7.309**
Missions:	2.839
Others Expenses:	2.558
Hardware & Software:	1.770
Other Equipment:	142

10^3 PTE

Funding:		**7.309**
OE/ITN	OF	474 (1)
External Projects:	1997	6.835

(1) This cost will be covered by external funding

ROTOR-FLOW INTERACTION

Theoretical Modeling of the Nonlinear Motions of Immersed Rotors

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Rotor vibration under moderate fluid confinement is an interesting problem, in connection with several important practical applications, such as immersed pumps (of fast-breeder reactors) and oil drilling machinery. For the geometries under consideration here — with a reduced gap $\delta = H/R$ of about 0.1 (H is the annular fluid gap and R is the rotor radius) — inertial effects are very important to the rotor-flow dynamics. This behavior contrasts with small-gap configurations ($\delta \approx 0.001$), such as found in bearings and seals, where dissipative effects are dominant.

In previous papers, the authors presented simplified theoretical models for both centered and eccentric systems, as well as extensive experiments on such systems. In those theoretical works, rotor dynamics were modeled using flow equations which were linearised on the gap-averaged fluctuating quantities. Also, a fully nonlinear model was developed for the specific case of planar motions. Experiments showed that the nonlinear terms of the flow enable better predictions of the rotor-dynamics at high spinning velocities, when approaching and beyond the instability boundaries.

Recently, the nonlinear approach has been extended to nonlinear orbital motions, using a rather involved theoretical formulation. The validity of the nonlinear model is currently being tested through numerical simulations in the time-domain. Also, new experiments are being prepared, in order validate the theoretical predictions. Several international publications have already been issued on these subjects.

Communication to: *ASME Symposium on Flow-Induced Vibrations,* Dallas, USA, November 1997. Submitted for publication in *Journal of Fluids and Structures.*

Experimental Identification of Rotor-Flow Coupling Forces

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To help qualify theoretical models developed to describe the dynamic behavior of systems it is important to be able to identify the parameters of the systems from experimental data. It is even more important when one is speaking of non-linear systems which are particularly difficult to analyze theoretically and experimentally. Quite a number of methods for linear and non-linear parameter identification exist.

In earlier work, we systematically tested several algorithms for non-linear system identification, which were inspired by the Rice & Fitzpatrick method, in order to assert their performance under noisy conditions. Suitability of the identification techniques has been thoroughly discussed, using numerical simulations as well as experiments. Extensive experimental results were presented and compared with theoretical predictions, based on the models previously developed by the authors.

For low or moderate shaft velocities, the linearised flow coefficients are in fair agreement with the theoretical predictions. Also, the experimental modal parameters closely follow the theoretical eigenvalues of the coupled system. However, for higher velocities, the identified flow coefficients dramatically depart from the theoretically predicted coefficients[(1)]. Recently, we developed a practical method — based on singular value decomposition and total-least-squares techniques — which enabled us to optimize the system excitation, in order to overcome ill-conditioning and improve the identifications[(2)].

(1) Paper presented at the *14th SMIRT - Applied Dynamicsin Reactor Technology,* Lyon, France, August 1997.
(2) *Commissariat à l'Energie Atomique (France),* Internal Report CEA/DMT/97-432, August 1997.

VIBRATION PROBLEMS IN POWER GENERATORS

Remote Identification of Impact Forces on Loosely Supported Systems

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Flow-induced vibration of heat-exchanger tube bundles and nuclear fuel is an important issue, concerning both component life and plant availability. Predictive methods have been developed to analyze the vibratory responses and wear, for realistic multi-supported configurations and flow excitations. Experimental validation of these methods involves very carefully instrumented test tubes and tube-supports, which is seldom possible in real field components, due to space limitations and severe environment conditions. Hence, there is a need for identification techniques that enable the diagnostic and field monitoring of tube-support interaction under real operating conditions, using information from motion transducers located far from the impact locations.

This is a very difficult problem, due ill-conditioning of the inverse problem, and also to the severe noise contamination of the measurements. We have developed techniques, based on response measurements at remote locations, for the experimental identification of the flexural wave-guide propagation parameters and for recovering the impact forces. Numerical simulations and experiments were presented, for *isolated impacts* as well as when the tubes display very *complex rattling* motions. Experiments show a good agreement between direct force measurements and the remotely identified impact forces*(1)*.

Recently, we have developed a new technique to deal with multi-supported systems. An iterative multiple-identification method is introduced, which operates in an alternate fashion between the time and frequency domains. This technique proved to be effective in isolating the impact forces generated at each gap support*(2)*. Experiments were performed on a long beam — with three clearance supports — excited by random forces. Beam motions were planar, with complex rattling at the supports. Experimental results are quite satisfactory, as the identified impact forces compare favorably with the direct measurements*(3)*.

(1) Paper presented at the *ASME Pressure Vessel and Piping Conference*, Orlando, USA, July 1997.

(2) Paper submitted for presentation at the *3rd Conference on Acoustical and Surveillance Methods and Diagnostic Techniques*, Senlis, France, October 1998.

(3) Paper submitted for presentation at the *ASME Pressure Vessel and Piping Conference*, S. Diego, USA, July 1998.

Theoretical and Experimental Analysis of Vibratory Problems in the Cooling of EDP/Setúbal Power Generators

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The cooling system of power generators at the EDP/Setúbal power station displayed excessive vibrations for several years, leading to costly breakdowns and plant unavailability. The portuguese power supplier EDP decided to contact ITN/Applied Dynamics Laboratory, in order to perform a thorough analysis of the problem and suggest adequate fixes.

In our study, we started by identifying the vibratory properties of the cooling system, which displayed a very high modal density. Some of these modes were resonantly excited by the unbalance and electromagnetic forces in the generators, at frequencies multiple of 50 Hz. Such excessive vibrations induced fatigue phenomena, leading to system breakdowns(1).

We then developed a simplified analytical model of the system, which enabled to predict the dynamic behavior as a function of the support parameters — e.g. number of supports, support mass, stiffness and damping. On the other hand, we used field data to construct a finite element model of the system, which confirmed the analytical predictions.

Therefore, suitable recommendations were provided, in order to modify the supports of the cooling system and stop excessive vibrations. These conclusions were experimentally validated using a laboratory experimental rig, which was developed. Results were found totally satisfactory(2).

(1) Instituto Tecnológico e Nuclear, Internal Report ITN/ADL-Jan97-1, January 1997.

(2) Instituto Tecnológico e Nuclear, Internal Report ITN/ADL-Nov97-1, November 1997.

EXPERIMENTAL MODAL ANALYSIS

Program ALADIN (Version 1)

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An essential step in the diagnosis of most vibratory problems is the modal analysis of the vibrating structures or machine components. Very often, theoretical methods (such as the finite element method) must be complemented — or even replaced — by the experimental identification of the system modes. This is a common problem, because important structural data or end-conditions, which are essential for analysis, are unknown or ill-defined. Hence, specific methods and software must be developed to cope with the need for experimental modes.

Following previous contracts with EDP/Companhia Portuguesa de Produção de Electricidade, *ADL* started a project for the development of software which will be used by EDP/CPPE engineers for modal identification of their power-station machinery. This project included the laboratory and field validation of the programme, as well as the theoretical and practical training of the program users. This project also includes the research of new techniques, in order to enable the modal identification of *working* machinery. This aspect leads to extremely interesting problems. The practical interest stems from the exceedingly high costs of plant immobilization.

The bulk of this project has been completed during 1996 and 1997. The computer code was developed, several identification algorithms were implemented, using both time-domain and frequency-domain vibratory data. The first working version of the program was delivered to EDP/CPPE, for field tests and user training. Currently, we are completing the programme debugging and documentation. Research on new methods for the modal identification of working machinery has begun, and will be pursued at least during 1998.

OTHER CURRENT WORK

Identification and Simulation of Complex Systems

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At the present time, a number of methods exist to identify the physical parameters of linear and non-linear systems. Concerning non-linear problems, these methods range from Volterra/Wiener series to parametric methods of the ARMA (Auto-Regressive Moving-Average) type. Most of these methods are very time-consuming and/or do not easily enable physical insight. Indeed, this is still — and will be, for quite a while — a very active research area. Recently, we started at *ADL* a project in this field, which is important to tackle many problems in applied dynamics.

Specifically, we are focused on very some promising nature-inspired identification and simulation techniques — neural networks and genetic methods — coupled with stochastic optimization methods such as simulated annealing. At the present time, in the context of a PhD thesis, we completed a review of current techniques and performed a number of dynamic simulations of linear and nonlinear systems. The preliminary work performed so far enabled us to identify several aspects worth further investigation, with specific applications in mind.

Internal Report ITN/ADL-Dez97-1, December 1997.