Parametric identification of nonlinear dynamic systems with application to an aircraft landing gear damper

Citation for published version (APA):
Verbeek, G., Kraker, de, A., & Campen, van, D. H. (1994). Parametric identification of nonlinear dynamic systems with application to an aircraft landing gear damper. In J. M. T. Thompson, & S. R. Bishop (Eds.), *Nonlinearity and chaos in engineering dynamics : [IUTAM symposium on nonlinearity and chaos in engineering dynamics, London, 19-23 July 1993]* (pp. 438-440). Wiley.

Document status and date:
Published: 01/01/1994

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 08. Feb. 2024

PARAMETRIC IDENTIFICATION OF NONLINEAR DYNAMIC SYSTEMS, WITH APPLICATION TO AN AIRCRAFT LANDING-GEAR DAMPER

G. Verbeek, A. de Kraker and D. H. van Campen
Eindhoven University of Technology, The Netherlands

For the experimental analysis of linear dynamic systems, it is common to employ shaker test procedures for the parameter identification or certification of a postulated model. The identification of nonlinear dynamic systems, however, is mostly performed by using various transient measurement signals, which are defined in order to resemble the actual or future trajectories of the system under consideration. In landing-gear manufacturing, for example, airworthiness authorities have defined a series of so-called drop-test procedures that will produce transient signals which resemble the operational conditions of the system during a landing. The drop-test facility could be used for identification or optimization of prototypes. Another approach for developing a design or certification tool analogous to the experimental analysis of linear systems, is the application of periodic loads in order to measure the corresponding periodic equilibrium solutions and/or outputs.

The identification method used here will be briefly addressed and consists of a combination of a Bayesian estimator (Bard 1974) and a periodic equilibrium solution technique based on time discretization (Fey 1992) or shooting. The Bayesian estimator utilizes the assumed deterministic mathematical model, the measured data, the assumed independent normally distributed residuals and prior knowledge concerning the parameters. The estimation problem can be reduced to a maximization problem (Verbeek 1991):

$$\Phi = \frac{1}{2}\left(- \sum_{\mu=1}^{n} \ln(\det V_\mu) - \sum_{\mu=1}^{n} e_\mu^T V_\mu^{-1} e_\mu - \ln \prod_{\alpha=1}^{l} \sigma_\alpha^2 - \sum_{\alpha=1}^{l} \frac{1}{\sigma_\alpha^2}(\theta_\alpha - \bar{\theta}_\alpha)^2 \right). \qquad (1)$$

Nonlinearity and Chaos in Engineering Dynamics
Edited by J. M. T. Thompson and S. R. Bishop,

In equation (1) n and l stand for the number of measurements and parameters respectively, e_μ are the residuals, V_μ are the covariance matrices, and σ_α and $\bar{\theta}_\alpha$ contain the prior normally distributed knowledge on the parameters θ_α. This maximization problem can be solved for the optimal parameters by modified Newton–Gauss iteration following the suggestions of Hendriks (1991).

This technique may be illustrated for axial measurements on an F16 nose landing-gear damper under periodic excitation. The experimental set-up for these tests will be discussed, as well as the choice of the experiments. First, the commonly used simple one-degree-of-freedom (1-DOF) dynamic model for this damper is postulated (Batill and Bacarro 1988):

$$\theta_1(\ddot{u}+g)+\theta_2|\dot{u}|\dot{u}+\theta_3\left[\frac{1}{1-\theta_4 u}\right]^{\theta_5}+\theta_6\arctan(\theta_7\dot{u})+\theta_8=F_{\mathrm{exc}}, \tag{2}$$

with output equation

$$\hat{y}=u+\theta_9, \tag{3}$$

in which u stands for the displacement and the θ_i's are the parameters. The gas spring force is based on the assumption of polytropic ideal gas behaviour and the friction force is modelled as 'continuous' coulomb friction. As in numerical simulations of these experiments, good results can be obtained with this model for identifications on a single frequency and amplitude, but the predictive power in other parts of the parameter or state space appears to be very low, because the assumption of polytropic gas behaviour is not met.

Re-evaluation of the measurement data leads to an improved 2- or 3-DOF model for the damper, which consists of the equation of motion, the first law of thermodynamics, and a constitutive relation for the pressure p, the displacement u and the temperature T, regarding solubility of gas in oil:

$$\begin{aligned}
&\theta_1(\ddot{u}+g)+\theta_2|\dot{u}|\dot{u}+\theta_3 p+(\theta_4+\theta_5 p)\sin(\theta_6\arctan(\theta_7\dot{u}))+\theta_8=F_{\mathrm{exc}},\\
&\dot{T}+\theta_9(T-T_0)+\frac{\theta_{10}T\dot{u}}{1-\theta_{11}u}=0,\\
&(1+\theta_{12}u+\theta_{13}T)p+\theta_{14}T=0.
\end{aligned} \tag{4}$$

In equations (4) the second and third terms in the energy balance stand for stationary heat flow through the damper wall and a heat source due to compression. The output equations are

$$\hat{y}=\begin{pmatrix}u+\theta_{15}\\ p+\theta_{16}\end{pmatrix}. \tag{5}$$

The new identification method described above is applied to both models for this landing-gear damper. For describing the observed physical phenomena, it can be concluded from the results that the thermodynamic model is superior to the commonly used one.

REFERENCES

Bard, Y. (1974) *Nonlinear Parameter Estimation*, New York, Academic Press.

Batill, S. M. and Bacarro, J. M. (1988) Modeling and identification of nonlinear dynamic systems with application to aircraft landing gear, *Structures, Structural Dynamics and Materials conference, 29th. Williamsburg, VA April 18–20.*

Fey, R. H. B. (1992) Steady-state behaviour of reduced dynamic systems with local nonlinearities. Ph.D. thesis, Eindhoven University of Technology.

Hendriks, M. A. N. H. (1991) Identification of the mechanical behaviour of solid materials. Ph.D. thesis, Eindhoven University of Technology.

Verbeek, G. (1991) Identification of mechanical systems by means of periodic excitation, *Euromech Symposium, 280. Lyon, October 28–31.* Balkema, Rotterdam.

G. Verbeek, A. de Kraker and D. H. van Campen, *Faculty of Mechanical Engineering, Section of Computational and Experimental Mechanics, Eindhoven University of Technology, PO Box 513, 5600 MB Eindhoven, The Netherlands.*