Mechanical Systems and Signal Processing 79 (2016) 30–46

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Cepstrum-based operational modal analysis revisited: A discussion on pole–zero models and the regeneration of frequency response functions

Wade A. Smith *, Robert B. Randall

School of Mechanical and Manufacturing Engineering, The University of New South Wales, Australia

ARTICLE INFO

Article history:
Received 15 February 2016
Accepted 20 February 2016
Available online 8 March 2016

Keywords:
Operational modal analysis
Frequency response function
Cepstrum
Anti-resonance
Transmissibility

ABSTRACT

Operational modal analysis (OMA) seeks to determine a structure's dynamic characteristics from response-only measurements, which comprise both excitation and transmission path effects. The cepstrum has been used successfully in a number of applications to separate these source and path effects, after which the poles and zeros of the transfer function can be obtained via a curve-fitting process. The contributions from the individual poles and zeros can then be added (in log magnitude) to regenerate the frequency response function (FRF). Cepstrum-based OMA was originally developed in the 1980s and 90s, but there have been a number of recent developments that warrant discussion and explanation, and this is the basis of the present paper, which focusses on the FRF regeneration process and on a number of broader points explaining FRFs from a pole–zero perspective.

The FRF regenerated from identified poles and zeros is subject to magnitude distortion from the effects of truncation, i.e., from the residual effects of out-of-band poles and zeros. As long as a reference FRF is available – for example from conventional experimental modal analysis or from a finite element model – this distortion can be corrected for using a magnitude equalisation curve. This paper discusses the nature of this equalisation curve, and gives recommendations on how best to obtain it. Other topics covered in the discussion are: the required distribution of poles and zeros for the successful regeneration of FRFs; node points and weak modes in a pole–zero model; the differences in pole–zero distribution between receptance, mobility and accelerance FRF forms; and, how to deal with the very low frequency region when regenerating FRFs. Special consideration is given to the identification of zeros – often masked by noise in response measurements – using transmissibility estimation. It is hoped that the discussion will assist in the application of cepstrum-based OMA methods and will lead to improved understanding of the FRF regeneration process and of frequency response functions more broadly.

© 2016 Elsevier Ltd. All rights reserved.

* Corresponding author. Tel.: +61 2 9385 6005; fax: +61 2 9663 1222.
E-mail address: wade.smith@unsw.edu.au (W.A. Smith).

http://dx.doi.org/10.1016/j.ymssp.2016.02.030
0888-3270/© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Cepstrum-based operational modal analysis (OMA) was developed in the 1990s [1–5], and has recently received further attention [6–9]. OMA seeks to determine the dynamic characteristics of a structure from response-only measurements, which comprise excitation and transmission path effects, which must be separated to obtain the latter. In certain cases, mostly involving a single input, the cepstrum can be used to conduct the separation, provided the two effects dominate distinct regions of the cepstrum. This relaxes the common assumption in OMA techniques that the input must be frequentially white.

Once the separation is complete, the frequency response functions (FRFs) of the system can be regenerated using the poles and zeros (resonances and anti-resonances) identified by curve-fitting the cepstrum of the corresponding transmission path. Through this process, the system is implicitly described using a pole–zero model, as opposed to the more common pole-residue model, the two being identical only for 'complete' models including all poles and zeros. Yet in practice there will almost inevitably be some truncation, in which only poles and zeros in a limited frequency band are used to describe the system as a whole. The FRFs regenerated from such a model have correctly located poles and zeros in the considered frequency band, but are subject to the effects of out-of-band poles and zeros, which manifest as a distortion of the general slope of the regenerated FRFs. Note that truncated pole-residue models have the opposite effect, in that poles and residues are more likely to be correct, but zeros are wrongly placed.

A number of techniques have been proposed to correct for this magnitude distortion, as outlined in Section 2.4 and addressed by the authors in Section 5. Through this process of refining techniques to regenerate FRFs from poles and zeros, the authors have identified a number of issues that warrant further discussion and explanation, and this is the basis of the present paper. It is hoped the discussion will assist in the application of cepstrum-based OMA methods and will lead to improved understanding of the FRF regeneration process.

2. Background on cepstrum-based operational modal analysis

2.1. The cepstrum defined

Various definitions for the cepstrum exist [10]; here we shall use the so-called 'real cepstrum' $\hat{x}$ and 'complex cepstrum' $\hat{x}_c$, defined for some time signal $x(t)$ as:

$$\hat{x}(\tau) = \Im^{-1}\left[\log\left(\left|X(f)\right|\right)\right] \text{ and } \hat{x}_c(\tau) = \Im^{-1}\left[\log(X(f))\right] \tag{1}$$

where $X(f) = \Im[x(t)]$ is the (complex-valued) Fourier transform of $x(t)$. Table 1 includes a number of terms often employed when using the cepstrum. Note that the real cepstrum includes no phase information, so the original time signal is not recoverable after liftering in the cepstrum domain (unless combined with the original phase; see Section 3.4). However, the process from the amplitude spectrum to the real cepstrum is reversible, and so the amplitude spectrum can be obtained after cepstral editing [11]. The 'complex' cepstrum is also real-valued, but includes phase information from the spectrum so is fully invertible; thus, $x(t)$ can be recovered after liftering the cepstrum.

2.2. Separation of source and path effects

While OMA possesses a number of advantages over experimental modal analysis (EMA) (where excitation forces are measured), its reliance on response-only measurements requires different techniques in order to extract modal properties. Response measurements, of course, typically comprise both excitation and transmission path effects, and these need to be separated before the structural properties can be determined.

For a linear time-invariant (LTI) system subjected to a single input $x(t)$, the system response $y(t)$ is the convolution of the input and the impulse response function $h(t)$:

$$y(t) = h(t) * x(t) = \int_{-\infty}^{\infty} h(\tau)\cdot x(t-\tau)\cdot d\tau \tag{2}$$

Table 1
Cepstrum terminology.

Frequency domain	**Cepstrum domain**
Frequency	Quefrency
Spectrum	Cepstrum
Harmonics	Rahmonics
Filtering	Liftering
Low-pass filter	Short-pass lifter
High-pass filter	Long-pass lifter

Download English Version:

https://daneshyari.com/en/article/559038

Download Persian Version:

https://daneshyari.com/article/559038

Daneshyari.com