Measurement 46 (2013) 2210–2222

Contents lists available at SciVerse ScienceDirect

Measurement

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

Transient suppression in FRF measurement: Comparison and analysis of four state-of-the-art methods

Griet Monteyne *, Gerd Vandersteen, Rik Pintelon, Diana Ugryumova

Vrije Universiteit Brussel, Department of ELEC, Pleinlaan 2, 1050 Brussel, Belgium

ARTICLE INFO

Article history:
Received 12 December 2012
Received in revised form 21 March 2013
Accepted 26 March 2013
Available online 17 April 2013

Keywords:
Non-parametric
System identification
Heat diffusion
Transient
Frequency response function

ABSTRACT

This paper compares four well selected methods for computing the non-parametric Frequency Response Function (FRF) of a periodically excited linear time invariant system. The suppression of the transient is mandatory when its influence in the data is large. Better suppression of the transient leads to a better non-parametric FRF estimate. A good non-parametric FRF estimate can be used to validate the parametric transfer function model in a second step. The suppression of the transient will be highlighted using the mean squared error of the non-parametric FRF estimate. Temperature transients caused by heat diffusion are used as example. The selected methods consist of two standard windowing methods and two methods based on the Local Polynomial Method (LPM). LPM was designed to find a non-parametric FRF estimate in the presence of nonlinearities. This paper will modify LPM to find a non-parametric FRF estimate for linear systems using a single experiment. The mean squared error of the four non-parametric FRF estimates will be compared and analyzed, based on a simulation and a measurement example.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Frequency response function measurements give quickly insight into the dynamic behavior of complex systems. A major issue in FRF measurements is the leakage (transient) error suppression. Given the (extremely) long transient period, in many cases waiting until steady state is reached before measuring is not an option. For example, the heat transfer in boreholes contains transients of typically 50 h. In spectral analysis techniques this problem is in general solved using time domain windowing [2,3]. Recently, more advanced techniques have been developed that reduce the leakage error either by modeling it locally by a rational function [11] or globally by an FIR filter [7,6]. This paper compares four well selected methods of two different types for computing the non-parametric Frequency Response Function (FRF). All the methods take the (long) transient effects into account, assume that the excitation signal is periodic, and require only one experiment.

An example of a system with a long transient is the heat diffusion in the ground near the borehole of a geothermal heat pump. To check the thermal balance of the ground, the heat diffusion phenomena need to be modeled [4]. Due to the large transients in the diffusion system, it is mandatory to take these transient effects in the data into account. These transient effects last long in diffusion phenomena since the transient decreases algebraically to zero as $O(t^{-3/2})$ [14,17,18].

Fig. 1 shows the temperature response to a periodic excitation. Note the large transient in the data. This transient was visualized by subtracting the last measured period of the temperature from the previously measured periods.

The first set of methods uses time domain windowing [8] to reduce the transient present in the data obtained from a periodically excited system. Since the leakage (transient) error is smooth as a function of the frequency, it can be reduced by a differencing operation in the frequency

* Corresponding author. Tel.: +32 2 6292949; fax: +32 2 6292850.
E-mail address: griet.monteyne@vub.ac.be (G. Monteyne).

0263-2241/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.measurement.2013.03.032

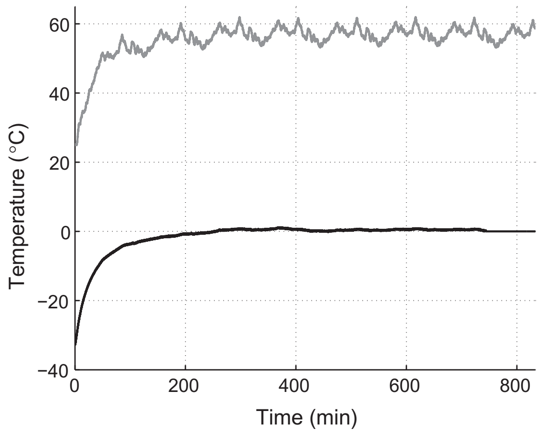

Fig. 1. Measured temperature (gray line) and transient contribution (black line).

domain. Therefore, one should select time domain windows resulting in a high order differencing in the frequency domain. Out of the different available windows, the Hann and the 4-term Blackman–Harris window are chosen.

The following two selection criteria are taken into account when choosing the windows:

1. The time domain representation should be a sum of a finite number of sines. This assures that the interpolation error is exactly zero provided that enough periods are measured.
2. Since the leakage (transient) is a smooth function of the frequency it can be reduced via differencing w.r.t. the frequency. Within the class of windows obeying criterion 1, those are selected that correspond to differencing w.r.t. the frequency. The order of the differencing should be high enough since the leakage error decreases with increasing order of the differencing. However, higher order differencing also requires more signal periods in order to avoid interpolation errors, as will be illustrated in the following paragraphs. Hence, a compromise between measurement length and leakage error suppression should be made.

The Hann window reduces the disturbing transient error via a second order differencing w.r.t. the frequency. The Blackman–Harris window reduces the disturbing transient error via a fourth order differencing. By comparing the results of both windows, the transient error reduction can be evaluated.

There exist windows that use even higher order differencing for the reduction of the transient, but they are not considered in this paper, since they require more than four measured periods in order to avoid systematic errors. When an estimate of the variance is desired, more than eight periods should be measured. This requirement would significantly increase the measurement time if the same frequency resolution is desired.

The use of overlap is not considered in this paper in order to simplify the analysis. It is expected that the use of overlap can lower the variance of the FRF estimate by maximum 3 dB [1]. However, it will not lower the bias error of the FRF estimate.

The second set of methods are based on the Local Polynomial Method (LPM) [15]. These LPM based methods (fast and robust LPM) eliminate the transient by assuming that its influence can locally be approximated by a low degree polynomial in the frequency domain. Till now the robust LPM was used to estimate the non-parametric FRF in the presence of nonlinearities. To estimate the influence of the nonlinearities at least two measurements of at least two periods are necessary. It will be seen that for a linear system, only one measurement of at least two periods is necessary in order to get a good non-parametric FRF estimate with the robust LPM. The fast LPM requires only one measurement of at least two periods to get a good non-parametric FRF estimate and can at the same time estimate the influence of the nonlinearities.

The non-parametric FRF estimate and the noise variance found via one of the four selected methods can be used to estimate and validate the parametric model [14,5]. This parametric model is needed to develop an optimal control strategy for the considered system, for example, a ground coupled heat pump [9].

There exist methods to find a parametric estimate of the system and its transient from the raw measured data. These techniques use a parametric model of the transient effect, either in the time [10] or the frequency domain [13]. One issue is the need for initial values for this kind of estimates. Good non-parametric estimates of the input and output spectrum together with their covariances can be used here to get better initial values, which reduces the probability to end up in a local (incorrect) minimum for the parametric FRF estimate [20]. The non-parametric FRF estimate can be used for the selection and validation of the parametric FRF estimate.

This paper compares different methods aiming to find a good non-parametric FRF estimate. It is assumed that the excitation signal is periodic and that the system is linear and time invariant. The main contributions of this paper are:

1. The LPM [15] was developed to estimate a non-parametric FRF of a system in the presence of nonlinearities. In this paper it will be used to obtain a non-parametric FRF estimate of a linear time invariant system. In the absence of nonlinearities, a single experiment is sufficient to estimate the non-parametric FRF via the robust LPM instead of at least two experiments in presence of nonlinearities.
2. A thorough analysis of the MSE of the non-parametric FRF estimates obtained with two standard windowing methods and two LPM based methods will be made. This extends the analysis in [12] where one windowing method and one LPM based method are analyzed.

First, the theory behind the different methods is briefly explained in Section 2. Next, the methods are compared in Section 3 by use of a simulation. Further, the non-parametric FRF methods are compared using experimental data described in Section 4.1. Finally, the results are compared and discussed in Section 4.2.

Download English Version:

https://daneshyari.com/en/article/10407420

Download Persian Version:

https://daneshyari.com/article/10407420

Daneshyari.com