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Dealing with periodical loads and harmonics in operational modal analysis using time-varying transmissibility functions

Wout Weijtjens [a], John Lataire [b], Christof Devriendt [a], Patrick Guillaume [a]

[a] Vrije Universiteit Brussel, Department of Mechanical Engineering, Acoustics and Vibration Research Group (AVRG), Belgium
[b] Vrije Universiteit Brussel, Department of Fundamental Electricity and Instrumentation (ELEC), Belgium

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ABSTRACT

Periodical loads, such as waves and rotating machinery, form a problem for operational modal analysis (OMA). In OMA only the vibrations of a structure of interest are measured and little to nothing is known about the loads causing these vibrations. Therefore, it is often assumed that all dynamics in the measured data are linked to the system of interest.

Periodical loads defy this assumption as their periodical behavior is often visible within the measured vibrations. As a consequence most OMA techniques falsely associate the dynamics of the periodical load with the system of interest. Without additional information about the load, one is not able to correctly differentiate between structural dynamics and the dynamics of the load. In several applications, e.g. turbines and helicopters, it was observed that because of periodical loads one was unable to correctly identify one or multiple modes.

Transmissibility based OMA (TOMA) is a completely different approach to OMA. By using transmissibility functions to estimate the structural dynamics of the system of interest, all influence of the load-spectrum can be eliminated. TOMA therefore allows to identify the modal parameters without being influenced by the presence of periodical loads, such as harmonics. One of the difficulties of TOMA is that the analyst is required to find two independent datasets, each associated with a different loading condition of the system of interest. This poses a dilemma for TOMA; how can an analyst identify two different loading conditions when little is known about the loads on the system?

This paper tackles that problem by assuming that the loading conditions vary continuously over time, e.g. the changing wind directions. From this assumption TOMA is developed into a time-varying framework. This development allows TOMA to not only cope with the continuously changing loading conditions. The time-varying framework also enables the identification of the modal parameters from a single dataset. Moreover, the time-varying TOMA approach can be implemented in such a way that the analyst no longer has to identify different loading conditions. For these combined reasons the time-varying TOMA is less dependent on the user and requires less testing time than the earlier TOMA-technique.

1. Introduction to dealing with periodical loads

In mechanical engineering, operational modal analysis (OMA) is used to retrieve the modal parameters of a structure that is subjected to loads associated with its proper use [1]. For instance a bridge excited by wind and traffic loads [1] or an

E-mail address: wweijtje@vub.ac.be (W. Weijtjens).

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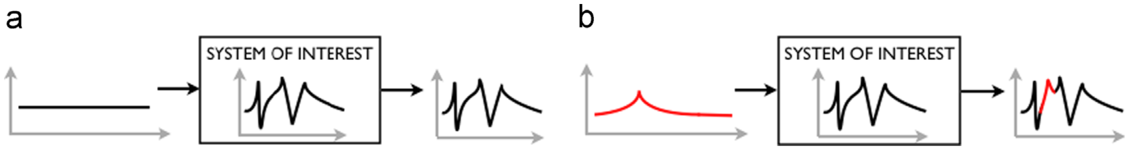

Fig. 1. (a) If the loads have a flat spectrum (i.e. white noise) all dynamics present in the measurements are caused by the system of interest. (b) For periodic loads this property no longer holds. Without any additional information about the loads, it is impossible to know whether certain dynamics are caused by the structure or by the load.

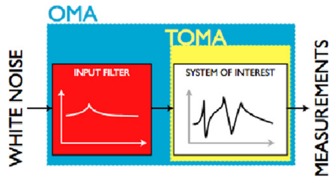

Fig. 2. Periodic loads can be modeled as the response of an input-filter to white noise. While OMA techniques will identify a combined system (input-filter + system of interest), TOMA-techniques are able to identify the system of interest directly no matter the input-filter.

offshore windturbine excited by wind and waves [2]. However, it is nearly impossible to correctly measure all loads that excite an operational structure. OMA therefore considers no known loads and operates purely on measured vibrations, i.e. the system response to the unknown loads. The identification of the modal parameters is made possible by assuming that the loads have a flat frequency spectrum, i.e. white noise [1]. This assumption is necessary to assure that the output spectrum resembles the transfer function of the system of interest, Fig. 1a. Therefore, all dynamics in the measurement spectrum are caused by the system of interest which then can be identified.

Because wind loads approximate such a flat frequency spectrum, OMA can be easily applied to bridges and tower-structures dominantly excited by wind [1,3]. However, some loads act periodically, e.g. waves and rotating machinery, and contain more energy at given frequencies (e.g. harmonics). This poses a problem for OMA, when nothing is known about the load-spectrum one cannot guarantee that all dynamics in the measurement-spectrum are related to the system of interest itself, Fig. 1b.

Several strategies are possible to still perform OMA in the presence of periodical loads. To illustrate them, one can model the non-flat spectrum of the load as the response of an unknown input filter to white noise, Fig. 2. A first strategy is to apply any of the classic OMA-algorithms [3–5] to the measurement data, without making any modifications to the algorithms. As a result the modal parameters of a system, that is the combination of the input filter and the system of interest, are identified. Afterwards the analyst can reject certain modes based on prior knowledge of the loads, e.g. rotational speeds [6], or the system itself.

An alternative strategy is to pre-process the measurement data to reduce the influence of the load as much as possible, before using the data into the preferred OMA-algorithm. Examples are time-synchronous averaging [7], cepstrum analysis [8] or interpolation in the frequency domain [9].

All previously mentioned strategies require that the peaks in the load spectrum are well-distanced from the actual structural dynamics, which unfortunately is not always the case. The solution to this issue can be achieved by adapting the OMA-algorithms to incorporate an input-filter next to the system of interest. In essence such an approach still identifies the combined system (input-filter + system of interest). However, as these algorithms include the input filter into the model, they are able to distinguish which dynamics are linked to the input filter and which dynamics are part of the system of interest. This allows for a better identification of the system of interest, especially when the periodical forces have frequencies close to structural modes [10–12]. However, all these methods assume a certain model of the input-filter and therefore require additional information about the load spectrum.

This paper will continue the work done in transmissibility based modal analysis, or TOMA [13,14]. TOMA-techniques solve the issue of periodical loads in a completely different manner. As discussed in [13] and [15] transmissibility functions can become completely independent of the input spectrum. This implies that TOMA is uninfluenced by the input filter and is able to identify the system of interest directly. Unlike all previous techniques the analyst does not require any additional information about the load spectrum to correctly identify the system of interest. The next section will recapitulate on TOMA and introduce a modification to the existing algorithms.

2. Transmissibility based OMA (TOMA)

In this section we will recapitulate the state of the art in TOMA, introduce the basic concept of time-varying TOMA and discuss its advantages.