Comparison of different Excitation Strategies in Operational Modal Analysis (OMA)

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Different ways of exciting a structure for the use in Operational Modal Analysis (OMA) are compared and evaluated on a simple structure. As in OMA the exact excitation is unknown, some assumptions about the excitation have to be made and it is very hard or even impossible to meet all theoretical requirements, such as randomness of the excitation in time and space. As a result, compromises have to be made. Therefore, multiple techniques are evaluated to give a recommendation for those who want to perform OMA measurements themselves.

Classical Experimental Modal Analysis (EMA) is performed as a reference, and we compare these results with those of OMA with different types of excitation. These are: tipping with fingers on the structure, brushing, and acoustic excitation with noise and different styles of music through a loudspeaker. The experimental results are evaluated using the Polymax algorithm for both EMA and OMA.

1 Introduction

Operational Modal Analysis (OMA) enables engineers to determine modal parameters of a structure (eigenfrequencies, modal damping, mode shapes) based on operational measurements. This means that, in contrast to Experimental Modal Analysis (EMA), the exciting forces acting on the structure are unknown. This is a very appropriate and common manner to analyze the dynamics of large structures, such as buildings and wind turbines which are typically excited through traffic or wind.

In the lab, OMA can be a useful method to do a quick modal analysis, if high precision and FRFs are not needed. When performing OMA measurements in the lab, one has to decide on how to excite the structure and the common literature gives no clear recommendation other than to use multiple input loads and record good quality data [1]. This is why, in the following, we investigate some different excitation strategies. The results can also help to better understand how an excitation’s characteristics influence the identification when working with OMA under environmental excitations.

2 Experimental Setup and Measurements

All measurements were conducted on a model sized wind turbine wing that was clamped at its root and held in a horizontal position with the leading edge pointing upwards (see Fig. 1). The modal analysis was carried out with the Polymax method (as integrated in the commercial software LMS Test.Lab), a frequency domain poly-reference identification technique [2]. The reference measurements yielded the following results: In the frequency range up to 500 Hz, the wing has 17 poles which are very well approximated by the synthesized modal model resulting from the identification.

After this reliable reference measurements, several different excitation techniques were applied: tapping with fingers, using a brush and excitation using a loudspeaker playing different types of music – classical (Symphonic Dances by Rachmaninov), electronic (Hovercraft by Deichkind), metal (Laid to Rest by Lamb of God, played on an electric guitar by the second author) – and noise.

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The loudspeaker, although already extremely loud, excited the structure only very lightly. Keep in mind, that the investigated wing is rather thin with a large surface area. It is therefore expected that acoustic excitation would in general not excite a structure as strongly as in our experiments.

It could also be shown that music is a very poor excitation technique in the context of OMA. This became obvious when comparing the stability diagrams for the different excitations. While both the brush and the finger tipping technique yielded very clear poles, the measurement system indicates a large amount of scattered identified poles for both the classical and the metal piece.

An explanation for this behavior can be found when looking at the spectra of the different songs used as excitations. In Figure 2, the spectrum of the classical music piece is shown. One clearly sees that frequencies over a wide frequency range are present, but there are clear peaks around certain discrete values. These discrete frequencies correspond to the only twelve notes per octave available in the common western scales. This renders the identification of structural poles extremely complicated because all those harmonics can be mistakenly identified as a pole as well. Structural poles, on the other hand, that lie between two musical peaks, and are thus poorly excited, probably will not be found by the identification algorithm.

A slightly different observation was made for noise and the electronic music piece. In these cases, only few poles were identified, but at least all poles found could be matched with structural poles from the EMA measurements. Noise and also electronic music (through its very distinct beat that acts similar to a series of impacts), in contrast, seem to spread their power much less biased over the frequency range. Still, their identification does not work well, most likely because the loudspeaker’s power output was not high enough despite the speaker working on full volume and already being subjectively hurtfully loud.

Fig. 2: Transient spectrum of Rachmaninov’s Symphonic Dances.

In the next step, we investigated how well the mode shapes resulting from the OMA measurements and those of the EMA analysis coincide. In order to quantify this resemblance, the Modal Assurance Criterion (MAC) was used. In Figure 3, the comparison between the reference measurements and those resulting from OMA based on the brush excitation is presented. Figure 3a is based on the results when all three directions of the sensors are used. The highest MAC values between the OMA modes and the reference modes are only around 60%. The MAC values grow to around 80% on the diagonal entries when all measurement channels recording in-plane movement are omitted (see Figure 3b), indicating that the movement in these directions is too small and the measurements thus rather noisy.

![Fig. 3: MAC values between the reference measurement and the OMA run with a brush.](image)

(a) MAC table using all three channels of each sensor  
(b) MAC table using only the z-directions of the sensors

3 Conclusion

The results of the presented study show that small PA system is not powerful enough to excite the investigated wind turbine wing effectively. Especially music was shown to be a poor choice as a vibration source. As a conclusion, the authors recommend a more direct, mechanical excitation as the resulting amplitudes on the structure yield far better measurements and thus more reliable modal identification results.
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