EDITORIAL

Operational Modal Analysis – a New Technique to Explore

***Rune Brincker**, Aalborg University*
***Nis Møller**, Brüel & Kjær*

In recent years, a new approach to the application of modal analysis has appeared. We call it "operational modal analysis." It is not beyond reason to ask if this is yet another "flash in the pan," but maybe, just maybe, it could be a very important advancement in this sophisticated application. Of course, the future will tell us what was right, what was wrong, and perhaps what we could have done better. It appears that the industry stands on the edge of a new era with new applications and a new basis for professional activity within the field of sound and vibration.

Operational modal is the name for the technique to do modal analysis on operational data – cases where we do not excite the structure artificially but just allow the natural operating loads to excite the structure. This is why new names are appearing, like ambient modal or natural input modal. It is also common to use the name "output only." We tend to dislike this name, since it gives the impression that there is no input – which is wrong. In reality, there is an inherent input in the output signal, but it is not as obvious as what is found in classical modal analysis techniques.

In the early days of modal analysis, the idea of operational modal was included in overall thinking. One could extract modal information in cases where the input was not exactly known. People were aware of this, and many of the old papers dealt with these cases. However, focus began to be placed on the input cases, since knowing the input eliminated the need for estimating it. Following this, people began to talk about SISO, SIMO and MIMO (single input single output, single input multiple output, multiple input multiple output). In this process, operational modal analysis was forgotten, except in a few cases where people were dealing with large structures. Civil engineers have no tradition for such testing as they tend to deal with prototype structures. In mechanical engineering, engineers developed techniques for exciting large structures like rockets, airplanes, and large machinery. In civil engineering where engineers dealt with stochastic (random) loads, it became a voodoo kind of analysis to extract modes from stochastic responses. Thus, since the beginning of the 1970s until the late 1990s, some development took place but it failed to arrive at any broad application in engineering. What was the reason for this? Probably because the industry lacked user-friendly tools.

Around the year 2000, several software companies began to develop tools for operational modal analysis, and little by little, it has reached the point where it is now an accepted technology. Currently, we have several conferences dealing solely with the subject, and multiple software solutions are available. Not only are they user friendly, but they also provide the user with many new possibilities.

What are these possibilities? Generally we can say that we get rid of the constraints of having to excite the structure artificially. It may require skilled personnel to get the excitation right. We are all afraid of testing problems such as double hits and DOF (degree of freedom) jitter when using a hammer and hours – and maybe even days – of work for setting up shakers as excitation sources. Hammer excitation is often 'sold' as an easy technique. When it come to real work, however, it is often the worst technique to use, since it has a high crest factor and excites the structure in a way that is not representative of damping and other structural properties. Therefore, to do things right may cost time and money.

Since everybody has to optimize their procedures economically as well as technically, it is worth considering if we can do modal analysis based on the natural-load technique only. If we could, we would save money, because it is costly to plan and carry out artificial excitation of a structure. If the structure has to be tested during normal operation, the owner also saves money because he does not have to close down his structure to perform the modal test. Or he may even be able to reuse data acquired for a test not intended for modal analysis. Finally, the results are often better, because they reflect the exact operational conditions for which the initial vibration problem was raised, including proper boundary conditions. Ultimately, we arrive at a more competitive solution to give us more realistic numbers.

So, there is a natural reason why people are using these new techniques – natural input or operational modal analysis. For civil engineers, it is easy to understand, especially for the ones who have tried to excite a large suspension bridge with a shaker! Some have invested a substantial amount of time, but it is extremely difficult, especially when attempting to excite low-frequency modes. For mechanical engineers, it is more like a supplementary tool for those occasions when a problem appears only under certain operational conditions. How would one plan to excite a structure to highlight the modes responsible for that problem? Again, it is really difficult, and performing operational modal analysis is a good solution to such problems. The only important question is: Can we trust the results from operational modal analysis? There is no rigorous mathematical proof; therefore, we rely on empirical proofs.

Overall experience gained over the last 5-6 years, where the techniques have been evolving, is in fact that the techniques work extremely well. The results are actually, and perhaps surprising to some, much better than one would expect. People who see the results of a modal analysis based on natural inputs are normally very surprised. They wonder why this can be true, which is a valid question. If we lose information about the inputs, then how can it be that the results are often as good or even better compared to traditional modal analysis? How is this possible? The answer is that what we lose through not knowing the loads, we gain on identification efficiency because of the mathematical strength in modern operational modal analysis tools. And even more importantly, we have better information about the modal properties in the recorded signals, because the loading is random in time and space.

We are dealing with *real* multiple inputs here. In fact, we should not call it multiple input; we should call it *poly-input*. Take an example of a car being driven across a bridge. It is exciting the bridge in *all* the points down that path, so we can be absolutely sure that *all* modes that have components in the vertical direction are excited. This clearly illustrates the potential for better results.

So what is on the other side of that

door? Is it worth it? The first question is "what can I do that I could not do before?" In responding to this question, we are ahead of ourselves a little and incorporating some of the advantages that will be made known to us in the future. Not all advantages are fully developed at this point but if we look at the full potential of the technique, we will be able to:

- Test large structures in operation.
- Do automated identification for monitoring.
- Estimate unknown loads on these structures.
- Estimate stresses and displacements in unmeasured points.

There are many more advantages yet to be discovered, but the advantages noted here should be enough for any serious engineer in the modal community to consider if he/she should look into the possibilities of this promising technology.

On the other hand, there are likely to be many more techniques to be learned. We should strive to add more to our professional knowledge of testing. We must think differently, since we cannot apply the lessons learned in traditional modal analysis techniques to operational modal analysis. One example is obvious: Do not try to limit the loading to one or two points – let the loading be free to move around, because it gives better results! If you do this, you limit the technique, and you will not be able to use its inherent power.

What is missing? We must admit that even though the technology has been around for some years, some answers are still missing. We need to obtain better tools for addressing outlying harmonics. We need user-friendly implementation for estimating the scaling factor of the mode shapes (the traditionally difficult technique of estimating the modal mass through conventional modal analysis techniques). We also lack the engineering knowledge on how to approach this method of testing. We are somewhat devoid of good, solid guidelines through a lack of available textbooks and formalized teaching.

This is a challenge for the profession. We need to take this new analysis tool and work with it to gain more experience. We need to overcome the obstacles that we are currently aware of and know that others will be placed in our path. Let us travel this journey from the traditional approach into this relatively unknown territory. Science has taught us that one can move forward by exploring new techniques, questioning the norm, and not be afraid to be different. By sowing seeds today, this new technique will quite possibly become the great harvest of tomorrow.

See you out there in the field – where the harvest is waiting! SV

The author may be contacted at: rb@svibs.com.