MODAL SPACE - IN OUR OWN LITTLE WORLD

by Pete Avitabile

Illustration by Mike Avitabile

Someone told me that operating modal analysis produces better results and that damping is much more realistic ?
Now this is something that needs discussion.

Now this is a topic that I have seen which causes some confusion among many people. These techniques are very powerful and can have very good results but ….. there are several issues that need to be clearly identified when using these tools that often slip by very quietly but can have very serious consequences if not understood. Let's discuss some of the critical items and issues of concern.

Over the past several years there have been many techniques developed which can reduce data from operating systems. These techniques have been previously referred to as "output only systems" or more recently as "operating modal characteristics". The critical feature of this type of analysis is that the input forces need not be measured in order to reduce the measured data to extract deformation characteristics. This is its biggest benefit ….. and also one of its downfalls. While there is no need to meaure the input, there is also no guarantee that the input exciting the system actual causes response of all the desired system characteristics. This can lead to definition of a system model that does not totally identify all the system characteristics – only those characteristics excited by the unmeasured/unknown force are estimated.

Figure 1 is a schematic we have used before to illustrate the input-output problem for a structural dynamic system. In output only systems, the output response is the only item measured. The assumption is that the input force is generally broadband and excites a frequency band that defines the operating characteristics of the system. However, in Figure 1, the input force (which is not measured) clearly does not excite all the low frequency modes of the system which may be critical to the definition of the dynamic characteristics of the system overall.

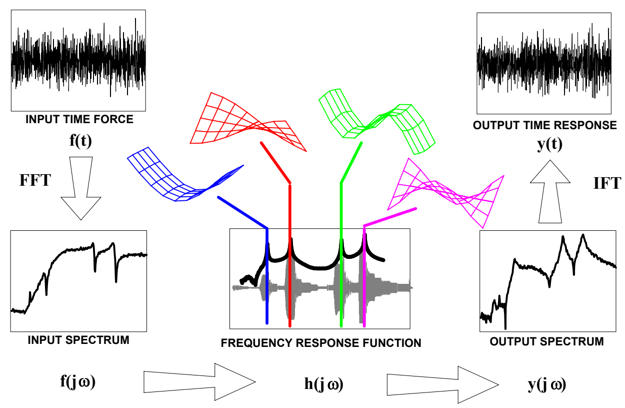

Figure 1 –Overall Response with Random Input Schematic

Well, this may not be a problem as long as this force is truly representative of the actual forcing function and there is no other possibility that the lower frequency modes may be excited by other operating forces. But the problem with output only systems is that you never really know what the excitation force is and if all the modes of the systems have been adequately excited for extraction of a model that completely describes the system characteristics.

So let's just realize that the forcing function is a concern and that it must be broadband in order to extract all the dynamic characteristics adequately. Provided that this is achieved then the modes that represent the system can likely be extracted. But another issue of concern is that there needs to be some way to scale the operating modal data to be used for any further dynamic simulations, correlations to a finite element model, forced response simulation or other dynamic analyses that require scaled mode shapes.

While there has been some research in this area, there still needs to be more work devoted to developing useful techniques that cover a broad range of situations and can provide scaled modes. Hopefully, future efforts will provide these tools.

So one additional critical item that needs to be discussed is related to the estimation of the pole of the system. While the frequency can be estimated relatively easily, the damping is not as simple at all. Many times I have heard people state that the damping obtained from an operating modal analysis is much more accurate that a traditional modal test. While this may be very true of systems that have nonlinear characteristics or bearings or other complicated construction features, the fact is that just about all of the operating extraction algorithms that are available ***all predict damping that appears to be higher than what actually exists*** in a linear time invariant (LTI) system.

To illustrate the fact that output only data reduction schemes always produce higher damping, even on an LTI system, results from two models will be presented here – one case is a pure analytical development of simulated operating data and the other is an actual experimental set up on a system which is extremely linear and for all practical purposes is an LTI system.

For the first case, let's assume that we can start with a linear time invariant system with analytically determined frequency and damping values. The damping will be specified to be 2% for this study. An analytically derived random signal can be applied to drive the LTI system and the output response can be computed. From this time data, a simulated set of data can be used to mimic the output only measurement process. This data can then be processed to extract system characteristics.

This analytical simulation was performed and the starting system characteristics along with the characteristics extracted from the simulated operating data produced the results in Table 1. While the frequencies and shapes are very good approximations of the LTI system, notice that the calculated damping from the output only system is much higher than the starting system. Obviously this is a result of the extraction process; the estimated damping from the output only system is higher than the original damping that was specified for the LTI system.

Table 1: Analytical Model - Prescribed 2% Critical Damping

Original Analytical Model		Random Operating Response	
Freq (Hz)	Damping	Freq (Hz)	Damping
9.1	2.0%	9.1	3.8%
32.5	2.0%	32.6	2.3%
60.3	2.0%	60.3	2.3%

In the second case, an experimental system was setup with a snowboard with no bindings or attachments to the board; this system is extremely linear with none of the typical joints or interactions of components that might cause the system to be nonlinear or appear to have more damping.

A traditional experimental modal test was performed first to estimate the system characteristics. Then a time stream of response (due to arbitrarily tapping the snowboard) was used to provide the simulated operating data. This output only data was processed and system characteristics were extracted.

The results of the traditional experimental modal test with the output only results are shown in Table 2. While the frequencies and mode shapes are very accurate, the damping estimates are not comparable at all. (NOTE: In both cases studies here, commonly used commercial extraction algorithms were employed to estimate parameters to produce the results)

Table 2: Comparison of Traditional Experimental Modal with Output Only Results for a Snowboard Configuration

Experimental Modal Results		Output Only System Response	
Freq (Hz)	Damping	Freq (Hz)	Damping
18.1	0.70%	18.2	2.44%
38.9	0.44%	38.8	1.73%
42.1	0.65%	42.2	1.71%
62.4	0.44%	62.0	2.0%
66.8	0.70%	67.5	2.0%

Now I know that I have presented only two cases here. But there have been many tests (and analyses) on numerous configurations that have substantiated this claim over the years. This may not always be the case but it appears to be true for almost all the cases I have seen thus far. So the most important item to note here is that, in general, output only systems tend to always predict much higher damping than what really exists – even in an LTI system. So please be very careful using the results from these operating modal analyses because the damping predicted may be higher than what really exists in the actual system.

As time progresses, these algorithms will improve and hopefully, they will provide more realistic results as time progresses. But in the meantime be careful using those results. I hope that this little discussion has shed some light on operating modal analysis (or output only systems). If you have any more questions on modal analysis, just ask me.