MODAL SPACE - IN OUR OWN LITTLE WORLD *by Pete Avitabile*

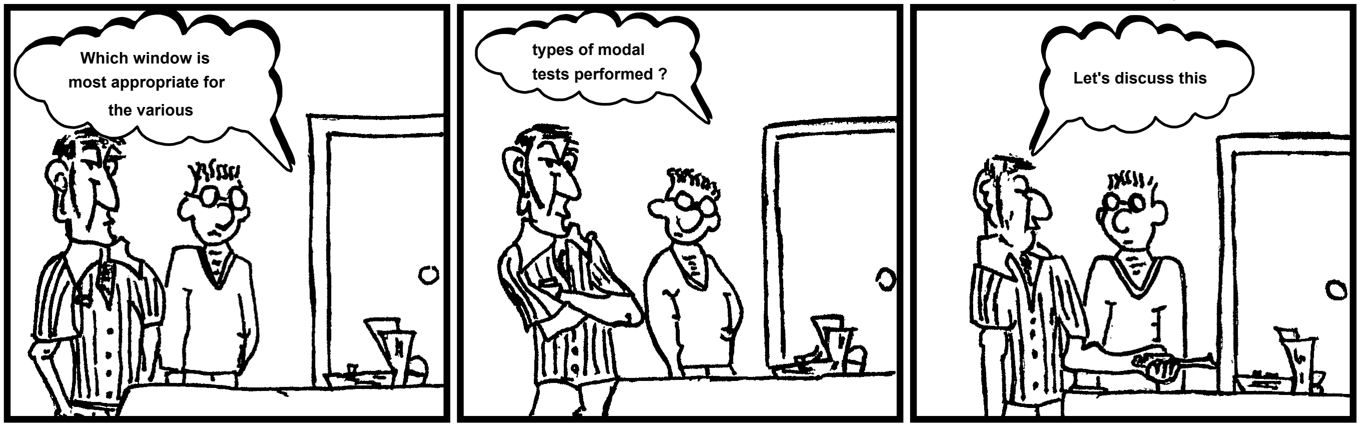

Illustration by Mike Avitabile

Which window is most appropriate for the various types of modal tests performed?
Let's discuss this

This is a good question. Let's review some of the commonly used excitation techniques and associated windows. Actually, the Fourier transformation using the FFT contains some constraints that must be considered first. It is these requirements that will help shed some light on why certain excitations are used and what windows are most appropriate.

First let's remember that the Fourier Transform is defined from $-\infty$ to $+\infty$. As long as the entire transient is measured ***or*** a repetition of the signal is captured, then the requirements of the FFT are satisfied. If this is not true, then there will be serious consequences from the most important signal processing problem called leakage. Windows are weighting functions that are used to *minimize* the effects of leakage - the effects of leakage can never be eliminated. This is really the problem that needs to be addressed. So with this basic fact, let's discuss the different types of excitation signals used for experimental modal testing and explain the windows typically employed for these excitations.

Impact testing is a very common testing technique that is often used for modal testing. Impact testing always causes some type of transient response that is the summation of damped exponential sine waves. This being the case, the entire transient event can be captured such that the FFT requirements can be met and leakage will not be a problem. But for most structures and especially, lightly damped structures, the exponentially decaying response often does not decay sufficiently within the sample record of captured data. This then implies that the FFT requirement may not be satisified. In these cases, an exponential window is typically applied to the data, thereby, weighting the data to better satisify the FFT requirement. Figure 1 shows an impact time pulse along with the raw time response and the exponentially windowed time response.

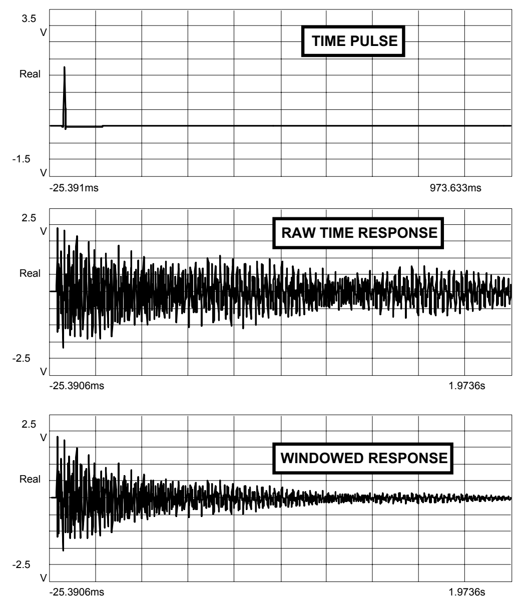

Figure 1 - Impact Excitation and Response

The exponentially windowed response has been weighted such that this signal better satisfies the requirement of the FFT process. The entire signal appears to have been captured - but at the price of the window function. Another alternative to applying the exponential window is to either adjust the bandwidth of the measurement to allow for more captured time data ***or*** increase the the total number of samples which has the direct effect of acquiring more time data. In any event, if the signal does not decay essentially to zero by the end of the sample period, then the exponential window may be necessary in order to minimize the effects of leakage.

In many data acquisition systems, there is also a force window that can be applied for the impact portion of the excitation. This force window is used to eliminate the effects of noise that may be present on the hammer excitation channel. Typically, this window is set to approximately 10% of the sample window such that the impact pulse is located within this unity gain window - that balance of the time record is weighted to zero. The force window may not always be necessary but is available on almost all data acquisition systems. It is very important to note that this window should ***never*** be used to try to remove the effects of a double impact that may occur during impact testing. Use of the impact force window to remove the effects of the second impact, resulting from a double impact, will seriously distort the input force spectrum.

Now that impact excitation has been addressed, let's discuss the window considerations for common shaker excitations used for experimental modal testing. The first most common one is random excitation. The problem with a random excitation is that there will ***never*** be a repetition of the signal within the sample interval. Therefore, a window will be required to minimize the effects of leakage.

The most common window used for random excitations is the Hanning window. But it must be pointed out that the use of a window, any window for that matter, will have an effect on the measured data - but the use of the window is a necessary evil in order to reduce the effects of leakage. Remember that the effects of leakage can only be minimized through the use of a window - it will never be eliminated. All windows will always have the effect of measuring amplitudes that are reduced from the true amplitude and, generally, have the effect of appearing to have more damping then what actually exists. A typical input-output measurement resulting from random excitation is shown in Figure 2 along with the application of the Hanning window on both the measured input and response channels. The use of the Hanning window can cause amplitude distortions of as much as 16%. Of course, this is much better than the distortion due to leakage if no window were applied.

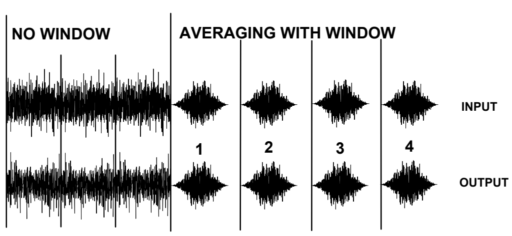

Figure 2 - Typical Random Measurement Sequence

Due to the problems associated with leakage and the measurement distortion through the use of windows, other excitations were developed that were specifically intended to eliminate leakage and the need for windows. Excitations such as pseudo random, periodic random, burst random, sine chirp and digital stepped sine were all developed. (All of these excitations will be discussed in some future article). The most commonly used excitation for modal testing today is burst random and will be discussed here.

The basic problem is that unless the entire transient is captured or a repetition of the data is captured, then there will be leakage. In one way or another all of the specialized excitation techniques attempt to satisify this requirement of the FFT. If this is satisfied, then there is no leakage and therefore, no need to apply any window weighting function. In the case of burst random, the excitation is applied to the structure in a manner whereby the excitation signal starts and stops within the sample interval. This directly implies that the basic requirement of the FFT process is completely satisfied; there is no leakage associated with this signal and no window weighting functions are required. Typically, a burst of 50% to 80% for the sample is customary and can be specified by the user. Now there is no leakage associated with the input excitation signal but some additional consideration must be given to the response channels.

The response of the structure does not stop instantaneously when the shaker excitation is terminated. Generally, there is some exponential decay that is seen to exist on the response channels after the shaker excitation is terminated. (In fact, there is also some measured force that is seen on the excitation channel after the shaker signal is terminated; this is part of the input that must be measured as part of the input forcing function.) A typical input-output burst random signal is shown in Figure 3.

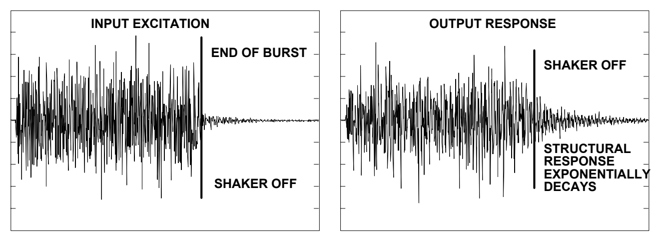

Figure 3 - Typical Burst Random Measurement Sequence

As long as the measured response decays essentialy to zero by the end of the sample period, then the entire signal is captured and there is no need to apply a window weighting function. However, if this is not the case then some adjustments are required. In order to have the entire transient be captured, then either the length of the excitation burst can be reduced, the bandwidth adjusted to provide more time data or more lines of resolution provided which essentially lengthens the captured time sample. All of these will generally help to assure that the entire response of the structure is captured within the sample of data collected. Generally, the use of windows for this excitation technique is not required. In fact the purpose of this excitation technique is to eliminate the use of any weighting functions. This will then provide a leakage free measurement that satisifies the periodicity requirement of the FFT process.

Now, I hope you understand which windows are most appropriate for these most commonly used experimental modal analysis excitation techniques. (Other excitations will be discussed in a future article.) If you have any other questions about modal analysis, just ask me.