MODAL SPACE - IN OUR OWN LITTLE WORLD

by Pete Avitabile

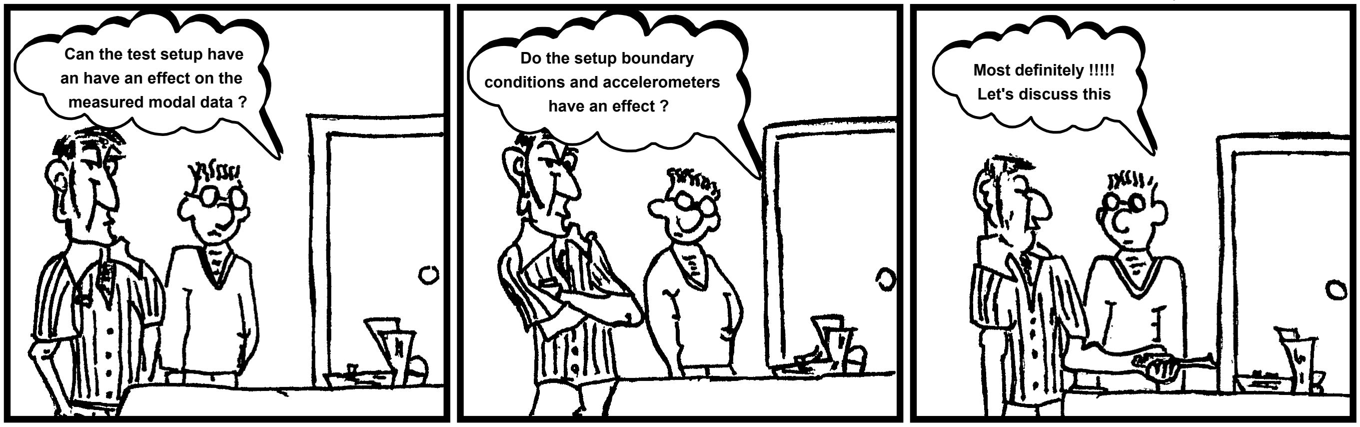

Illustration by Mike Avitabile

Can the test setup have an effect on the measured modal data ?
Do the setup boundary conditions and accelerometers have an effect?
Most definitely !!!!!   Let's discuss this

There is no doubt that the test setup and instrumentation may have an effect on the measured data. This is especially true when testing items such as disk drives, turbine blades, cabinets, computer boards and other small lightweight structures.

While it may be obvious to a seasoned test engineer that the test setup and instrumentation may have an effect on the results of a modal test, this may not necessarily be obvious to the new test engineer to modal testing. (I recently read a report of an experimental modal test on a light weight structure where, after many different tests and analyses were performed, it was "revealed" that the accelerometer mass had an effect on the natural frequency measured on the test article. So it is definitely worthwhile to discuss this further.)

From a practical standpoint, it is straightforward to realize that the instrumentation that is applied to the structure during the test is a direct addition of mass to the structure. However, many times I am shocked that most test engineers new to modal testing just don't realize this fact. For some reason, the instrumentation is perceived as non-intrusive. But, in fact, the instrumentation that is mounted on the structure can, in many instances, have an effect on the measured frequency response functions. From a theoretical standpoint, the natural frequency is related to the square root of the ratio of stiffness to mass. So it stands to reason that if the mass of an accelerometer is "added" to the structure to make a measurement, then the natural frequency will be lowered. Obviously, the larger the accelerometer mass, the more pronounced and obvious the shift of the frequency. And, of course, the size of the test article will have an effect on this. If an accelerometer is added to a large massive structure, such as a bridge or building, then the effects of the accelerometer are likely negligible. But, as the size and mass of the structure under test becomes smaller, then the effect of the accelerometer mass becomes much more important.

It is also very important to note that the mass of the structure is not necessarily the entire mass of the structure but rather the effective mass of the "modally" active portion of the structure. For instance, consider the modal test of a large computer rack with disk drives and computer boards. The mass of the accelerometer on the main structural portions of the rack may not pose any problems. However, the weight of the accelerometer on a cabinet panel or on a computer board or on the armature of the disk drive may have a significant effect on the measured frequencies. Often people get confused by thinking that the mass of the accelerometer is related to the total mass of the structure. This is not the case. It is the mass of the accelerometer relative to the mass of the modally active portion of the structure which may be vastly different than the total mass of the entire structure.

The best way to illustrate the accelerometer mass effect is go down to the lab and take a measurement. To illustrate the mass loading effect, a lightweight disk drive bracket was used for measurement purposes. This was a rectangular structure approximately 5in x 3in x 2in high used for mounting some older disk drives. (Now these measurements are not my pride and joy, but they will clearly illustrate the point.)

A very lightweight, a reasonably lightweight and heavier accelerometer were attached to an open span on the side of the bracket. Three separate impact tests were performed to obtain typical measurements. Only impact excitation and accelerometer response were measured in the x-direction to obtain the drive point measurement shown. Two measurements for the extreme mass cases are shown in Figure 1. The arrows depict two frequencies, for example, that were measured to be 260 Hz (red) and 271 Hz (blue); the third intermediate measurement with a frequency of 266 Hz is not shown. For this frequency, there exists significant difference. So the mass of the accelerometer can have a significant effect; the higher frequencies are effected by an even greater degree.

Another important note is that the two lower amplitude frequencies shown do not appear to be significantly affected by the mass of the accelerometers. These two modes are either y-direction or z-direction predominant in their response. Since the drive point measurement was only obtained in the x-direction, then the mass of the accelerometer is essentially located at the node of the mode for the lower amplitude frequencies and therefore has negligible effect.

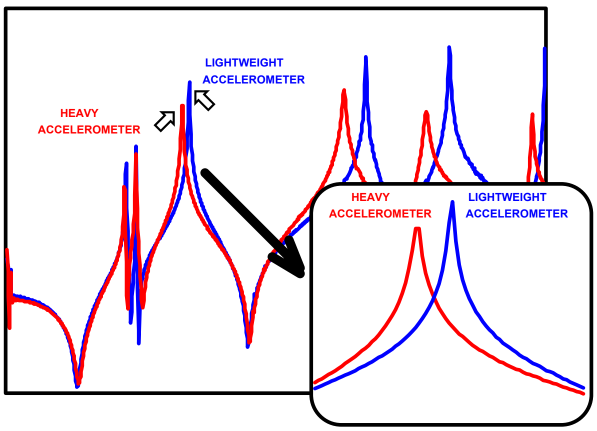

Figure 1 - FRF with Two Different Accelerometer Masses

Therefore, two important items result from this simple test that was performed. First, the mass of the accelerometer has an effect. This must be true since the equation defining the natural frequency of any system involves both the stiffness and mass. Second, the location of the mass of the accelerometer will also have an effect. If the mass is located at the node of a mode (point of zero amplitude), then the mass addition will have no effect *on that mode*. If the mass of the accelerometer is located at the anti-node of a mode (point of maximum amplitude), then it will have the largest effect *on that mode*.

Of course, mass loading effects can pose problems especially if accurate frequency measurements are required. The use of noncontacting (or less intrusive) measuring devices can be used to measure the natural frequencies. For instance, a laser device can be used to obtain high quality FRF measurements without causing any mass loading effects on the structure. However, these devices are typically very expensive and not found in every lab. Other measurements can also be made using eddy current probes or strain gages with reasonably good results. However, these are not always as convenient to apply to the structure under test.

How can the effects of mass loading be identified? Well, the easiest way is to mount two accelerometers at the same location on the structure. Take one FRF measurement with both accelerometers and a second measurement with only one accelerometer. This will quickly identify whether or not the mass loading will be an issue. Then some corrective measures need to be taken if this poses a problem. (Further discussion of this is beyond the scope of this article and will be addressed at some future point in time.)

But there is another item that I feel is just as important as the accelerometer mass loading effect that *is almost always overlooked*. Many modal tests are conducted in a "free-free" condition. Actually, there is no way we can do this here on earth. At best, we can simulate something that is reasonably close to unconstrained (free-free).

Several tests were performed with different mechanisms for supporting the bracket. Three FRFs are shown in Figure 2. The bracket was supported on thick foam (green), airbag packing material (red) and hung from rubberbands (blue). (The same frequency range as used for the mass loading discussion will be addressed here.) The frequencies depicted ranged in frequency from 266 Hz to 272 Hz (and the amplitude is substantially different). This is just about the same amount of frequency variation observed with the accelerometer mass effects!!! So when everyone gets all upset about mass loading effects but don't even consider the support mechanism for the structure, I laugh to myself (and then provide some helpful thoughts to consider). Clearly, the support variation is as critical as the accelerometer mass loading effects. In many cases, the support mechanism effects are much more important than the mass loading effects - *so be careful !!!*

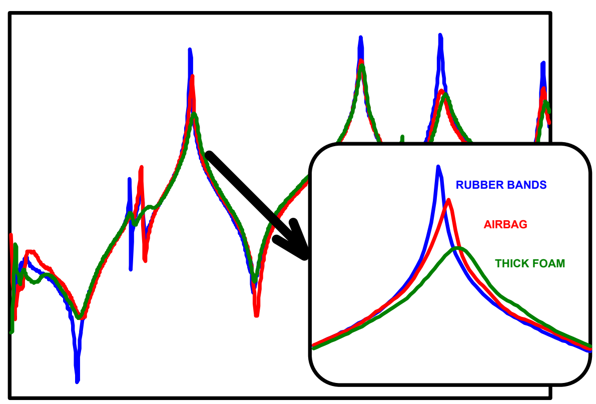

Figure 2 - FRF with Three Different Supports

Now these measurements were just made using what I had available in the lab to quickly show you this problem. It didn't take much effort at all to illustrate the problem of mass loading. But also realize that the support system used to hold the structure in a "free-free" condition is equally important. I hope this helps to answer your question concerning test setup. If you have any other questions about modal analysis, just ask me.