
Illustration by Mike Avitabile

So now I have another question…if the hammer impacts a node, then there is no response elsewhere? That seems incorrect. OK… let's discuss this further.

So last time we discussed how the roving hammer test is a great way to run a modal test but that you needed to be very careful to not place the reference accelerometer at the node of a mode. We also discussed that it didn't matter how many points we impacted if the reference transducer was at the node of a mode then we would not see that mode.

So in answering the question I also stated that the same would be true for a stationary hammer test with a roving accelerometer. You still needed to make sure that the stationary hammer input at the reference location was not at the node of a mode – or else you would not see any response from that mode.

After we finished discussing it you seemed to not be comfortable with the fact that you could hit the structure at a node point and the structure would not move at that point and you mentioned it was counter-intuitive to you. So let me give a few more examples to try to get you more comfortable with this fact.

I will use a simple free-free beam and a simple plate to try to drive home some additional points for you. Let's first recall the FRF equation we wrote last time which can be in terms of the residues or mode shapes. But in this residue form of the equation, it is not so clear so I prefer the mode shape form of the equation because it is there that you can clearly see the effect of the mode shape on the peaks in the FRF for each of the modes.

$$h(s)_{ij}\Big|_{s=j\omega} = h_{ij}(j\omega) = \sum_{k=1}^{m} \frac{q_k u_{ik} u_{ij}}{(j\omega - p_k)} + \frac{q_k^* u_{ik}^* u_{jk}^*}{(j\omega - p_k^*)}$$

This equation is very clear in that the amplitude of the FRF is very much controlled by the ***value of the mode shape at the output response location*** times the ***value of the mode shape at the input excitation location***.

So now let's consider a simple free-free beam. A series of measurements will be made at 15 equispaced points along the length of the beam. The measurements will be made and then the FRFs will be plotted in a waterfall plot so the shape can be clearly seen. And in order to see this, it is very important that we use the imaginary part of the FRF to map the mode shape. We may want to recall that the imaginary part of the FRF will be a peak at the natural frequency while the real part of the FRF will be a zero; this is true only for displacement and acceleration measurements. Now FRF measurements were made over a wide frequency band but I want to zoom in to just around the resonant frequency for the first and second mode for this free-free beam.

Figure 1 (blue) shows the waterfall plot of the imaginary part of the FRF for all 15 measurments with a frequency band around the 45 Hz first mode. Figure 2 (red) shows the same plot but with a frequency band around the 140 Hz second mode. In both plots the peak of the imaginary part of the FRF is circled for all the measurements made on the beam. In Figure 1 (blue), it is very clear that the shape is that of the first free-free flexible mode of the beam whereas Figure 2 (red) very clearly shows the second free-free flexible mode of the beam. The most important thing to note right now is that the amplitude of the imaginary part of the FRF for mode 1 changes sign from positive to negative back to positive as you traverse down the length of the beam. At some point it crosses zero. At this location, there is no response for that particular mode. And it doesn't matter if it identified with a hammer input or accelerometer output.
***The FRF will be zero at that point for that mode.***

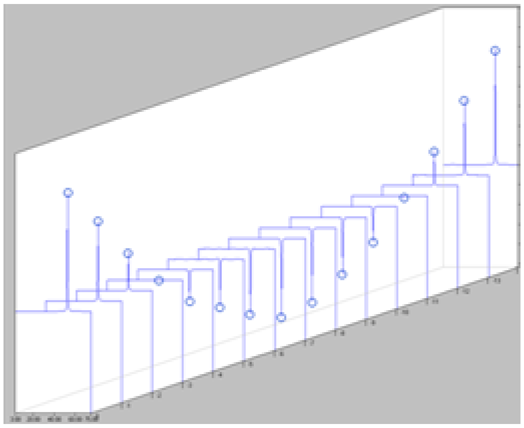

Figure 1 Waterfall plot of the Imaginary Part of the FRF showing the First Mode Shape

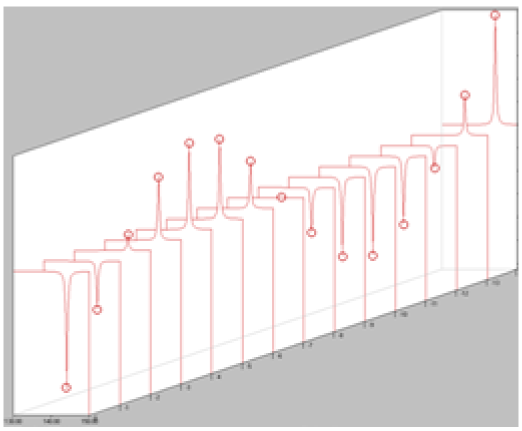

Figure 2 Waterfall plot of the Imaginary Part of the FRF showing the Second Mode Shape

So the node of the mode is a special location where there is no output for that mode. And it doesn't matter if you measure with an accelerometer or impact with a force hammer – there is no response because the value of the mode shape at either the output response point or at the input excitation point is zero and therefore there will be no peak amplitude for that mode. But there may be some response at that point due to the other modes of the structure which may not be related to the node of those other modes.

So in the case of the roving hammer, if the accelerometer is located at the node of a mode then it doesn't matter how many points are used for the hammer excitation, there will be no contribution to the response due to that particular mode.

And the converse is also true. If you have a stationary input that is located at the node of a mode, it doesn't matter how many points are measured with the response accelerometers, there will be no contribution to the response due to that particular mode.

So now let's extend it from the beam to a plate to see the same effect. A rectangular plate has been used in previous articles and is used here for this example. Figure 3 shows 6 FRF measurements around the perimeter of the plate where the first peak is related to the first bending mode of the plate (blue) and Figure 4 shows the same information but highlights the second mode of the plate (red).

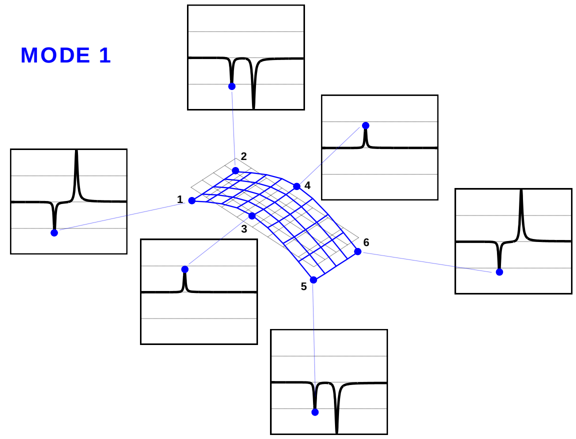


Figure 3 Plate Bending Mode

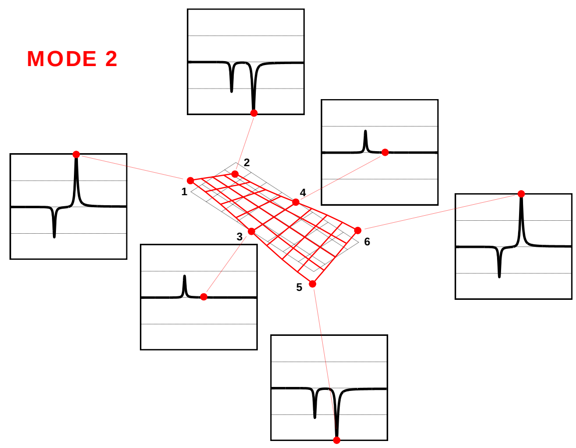


Figure 4 Plate Torsion Mode

So in looking at Figure 3 and 4, the same statements can be made regarding the node of the mode and the impact or response location. The mode shape can be simply described by plotting the imaginary part of the FRF. The function has positive and negative values depending of the mode shape of the structure. There must be a zero crossing at some point which corresponds to the node of the mode – this implies a point of zero response for that particular mode. And the response is zero at the node of the mode whether the measurement is related to the response accelerometer location of the hammer impact location – but just for that particular mode.

I hope that this helps to further explain these questions you had. If you have any other questions about modal analysis, just ask me.