WHITE PAPER

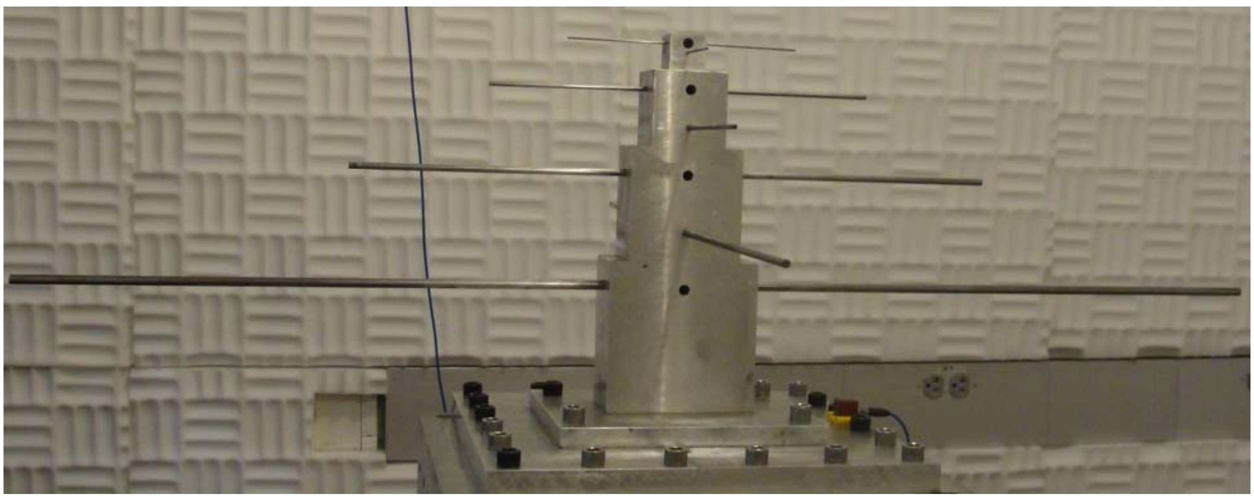
Monitoring Structural Dynamics with a Microphone

By Rene Chiquillo, Jr.

Monitoring Structural Dynamics with a Microphone

This Tech Note describes a laboratory experiment developed at Texas Christian University (TCU) intended to mentor students in the fundamentals of beam vibration and the resultant natural frequencies (eigenvalues) and associated mode shapes (eigenshapes).

The background of this experiment involves the derivation of the equation of motion for a beam, specifically the solution form for a beam clamped on one end and free on the other. In order for students to understand how the dimensions of different rods affect the eigenvalues (natural frequencies) of the system, the Christmas tree was introduced. The Christmas tree is a structure made of steel, which holds 14 horizontally clamped rods (7 symmetric pairs). The rods vary in length and diameter therefore affecting the parameters for the natural frequency equations.



The Christmas tree holds a total of 14 rods. There are seven different lengths.

The laboratory experiment preparation began with the theoretical calculation of the first two natural frequencies of each rod. In order to understand the results (eigenshapes and eigenvalues), the students were lectured on the Bernoulli-Euler Beam equations. The students understood that the length, area moment of inertia, Young's Modulus of the material, and mass per unit length are the parameters that define each natural frequency.

The original purpose of the Christmas tree experiment was to enable students to visually analyze the transverse response of the cantilevered rods under sine and random vibrations. The sine and random vibrations are created by an LDS electrodynamic shaker (Model 850-440T, S/N S8605-001). The shaker is operated with a LDS Dactron controller (Model 7933257 1228), which allows the user to input sine or random vibrations with determined specifications. The motion of the shaker is monitored by an accelerometer mounted on the base of our Christmas tree structure. The top of the shaker holds a 170 lb tapped magnesium block. The Christmas tree structure is bolted to the block applying a 25 lbf·ft torque to each bolt (shown above).

The shaker has the following specifications:

Maximum Displacement: 1 inch 0 to Pk
Maximum Force: 5000 lbf
Frequency Range: 5 – 3000 Hz
Air-cooled

Experiment parameters:

The sine vibration experiment is set at 3Gs with a frequency range from 10 to 500 Hz. The experiment is conducted with a sweep rate of 0.4 oct/min.

The sensitivity of the PCB accelerometer (Model TLC333B42, S/N 41215) at the base of the Christmas tree is 495 mV/g.

LDS electrodynamic shaker with Christmas tree bolted to magnesium block.

The students have previously estimated the first two resonant frequencies of each rod using the Bernoulli-Euler equations. When the sine vibration experiment begins the students will look for the resonant frequency of each of the rods and record the frequencies they occur at. The students will make use of closed circuit television to monitor the resonance of the rods.

After performing the experiment the students were able to record and correlate the following information:

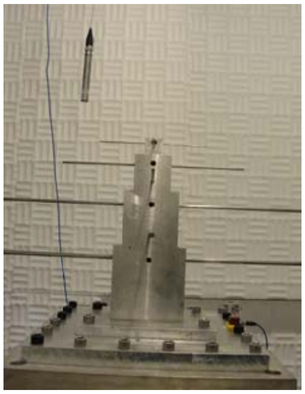
				First Run	First Run
Rod	**Length (in.)**	**1st Resonance Hz (Estimated)**	**2nd Resonance Hz (Estimated)**	**1st Resonance Hz (Experimental)**	**2nd Resonance Hz (Experimental)**
1	15.25	30.536	191.379	28.8	Unrecorded
2	9.375	60.358	378.286	57	330
3	7.25	100.928	632.539	91.1	-
4	4.845	150.661	-	141.2	-
5	4.182	202.218	-	180	-
6	2.64	253.717	-	Unrecorded	-
7	2.42	301.945	-	Unrecorded	-

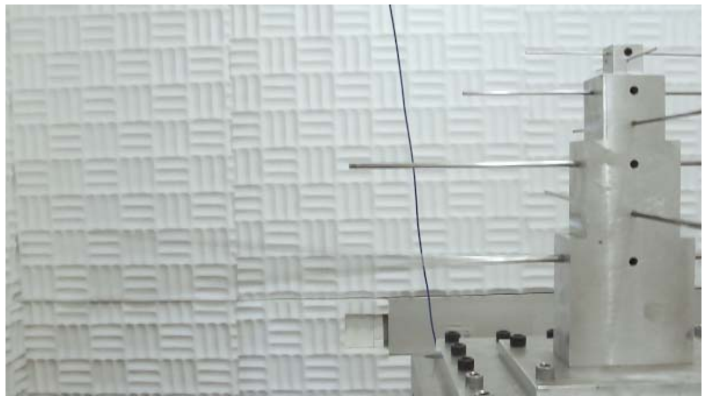
The students were not able to record data for rods 6 and 7 which have the shortest lengths. Also the second resonance of the longest bar went unrecorded. The rods become stiffer as their lengths were shortened. The shortest rods have higher resonant frequencies making it challenging for the human eye to detect maximum displacement. This fact can be described by the peak acceleration equation below:

Equation 1

X = Displacement
A = Maximum Amplitude
ω = Frequency (rad/s)

In order to experimentally determine the resonant frequencies of the shortest rods the use of a microphone was considered. The use of accelerometers was disregarded due to the fact that their mass loading would change the structural dynamics of the Christmas tree.





The picture to the above left shows the PCB microphone (Model Y378A13, S/N U103169) set up. The picture to the right visually shows the first resonance of the bottom rod (15.25 in).

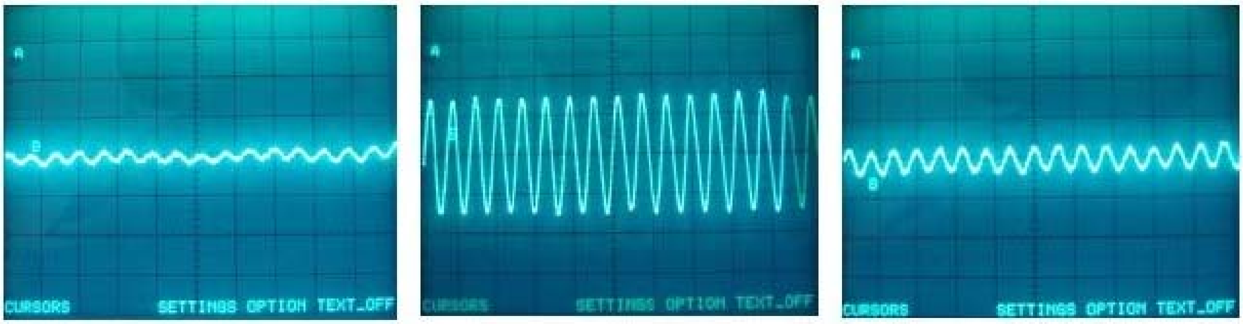
The PCB microphone received input power and regulated output through the use of the PCB amplifier (Model 464A, S/N 1503). A Philips scope (Model Fluke PM335, S/N S8605-001) was connected to the ICP output of the PCB amplifier in order to monitor the microphone's response.

With the PCB microphone set up the experiment was run a second time using the same parameters from the first run. The students made use of the closed circuit television system and Phillips scope to monitor and record the resonant frequencies. The results obtained were the following:

				Second Run w/Microphone	**Second Run w/Microphone**
Rod	**Length (in.)**	**1st Resonance Hz (Estimated)**	**2nd Resonance Hz (Estimated)**	**1st Resonance Hz (Experimental)**	**2nd Resonance Hz (Experimental)**
1	15.25	30.536	191.379	28.8	180
2	9.375	60.358	378.286	56.78	322
3	7.25	100.928	632.539	89.7	-
4	4.845	150.661	-	140	-
5	4.182	202.218	-	180	-
6	2.64	253.717	-	260	-
7	2.42	301.945	-	275	-

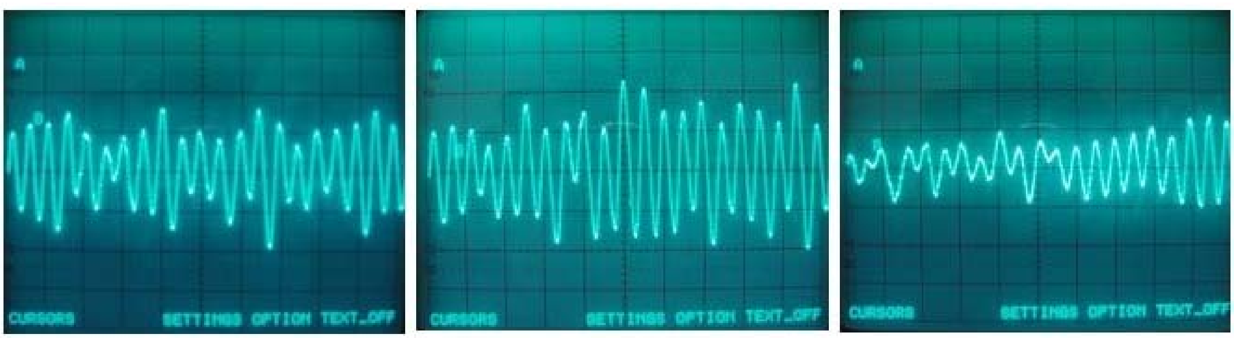
The use of the PCB microphone subsequently allowed students to record values for the resonant frequencies of the shortest rods. The second resonant frequencies of rods 1 and 2 were also recorded. The second resonant frequencies present more difficulty to monitor than the first because of the presence of nodes in the mode shapes (eigenshapes).

It is important to note that the microphone became more important as the experimental frequencies increased. Again, Equation 1 explains this fact. Low operating frequencies require higher amplitude motion from the electrodynamic shaker in order to generate the constant 3Gs acceleration stimulus. This high amplitude shaker motion creates pressure disturbances obscuring the sound waves attributable to the low frequency resonances of the longer rods. Conversely, higher operating frequencies require less shaker motion at the same 3G level. Therefore, when the shorter test specimens attained their higher frequency resonances, the microphone effectively detects the sound waves created by the rods' transverse displacement.



The pictures above are a chronological representation of the PCB microphone response in a time lapse of 7 seconds. The images display the second resonant frequency (center) of the 9.375 in rod. The parameters of the Philips scope were kept constant at 0.5V/div and 5ms/div.

For the random vibration experiment the electrodynamic shaker was programmed to input 0.02 G^2/Hz acceleration for a frequency range of 15 to 500 Hz. The resulting power spectrum provided a 3.0771 GRMS level. All rod transverse modes were excited simultaneously.



The pictures above display at various times the response of the PCB microphone to random input vibrations.

The PCB microphone (Model Y378A13, S/N U103169) proved to be an extremely useful tool for the laboratory experiment of monitoring structural dynamics. Students were able to correlate the estimated data with the experimental data and understand how the dimensions of a geometric body define its resonant frequency and respective mode shape.

In order to make the most out of the laboratory experiment, students also need to understand the physics behind the events and the equations that govern these events.

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