AC 2012-4042: DEVELOPING EXPERIMENTS FOR THE VIBRATION COURSE WITH MINIMAL EXPENDITURE

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Developing Experiments for the Vibration Course with Minimal Expenditure

Abstract:

The Engineering Technology (ET) program at Middle Tennessee State University (MTSU) has approximately 410 students. Our Mechanical Engineering Technology (MET) concentration was started in 2004 fall and currently it has 200 majors. All MET students are required to take Vibration along with several other senior level courses. Vibration is designed as a lecture/lab course however there has been limited lab experience provided to students. Three years ago the author developed the Helmholtz resonator project in which student teams are required to design, build and test a Helmholtz resonator. The purpose of this project was to further develop the lab portion of the MET program. Several vibration instruments were donated to the University including a sound and vibration analyzer, a digital sound level meter, a microphone preamp, two microphones, an accelerometer, and cables and connectors for use in our Vibration course. In consultation with the author, the co-author developed five experiments that could be run in a classroom or lab, and received credit towards his capstone project.

In the first experiment, the students familiarize themselves with the instrumentation and the free frequency analysis software, Audacity. In the second experiment, they learn to record time domain data and perform frequency analysis. In the third experiment, they learn to use the accelerometer in vibration measurement. In the fourth experiment, the students learn to perform noise analysis of an internal combustion engine exhaust system. In the fifth experiment they learn to perform spectrum analysis for different noise and vibration signals. The donated equipment and instrumentation used in these processes are slightly old but functional and met the lab requirements of our Vibration course. The experiments meet the student learning outcomes *c* and *g* of the ABET *a-k* criteria.

Introduction:

Middle Tennessee State University is one of the fastest growing universities in the United States. We have about 26,000 students and our Engineering Technology (ET) is one of the ten departments in the college of Basic and Applied Sciences. The ET program has Computer, Electro-Mechanical and Mechanical concentrations with approximately 410 students. The Mechanical Engineering Technology (MET) concentration has approximately 200 majors. The MET program, started in the fall of 2004, has grown well and we are fortunate to be located in a highly industrialized area. Our MET students are required to take several senior level classes such as Design of Machine Elements, CADD, Fluid Power, Heating, Ventilation and Air Conditioning (HVAC), Robotics, and Mechanical Vibration. We started teaching Vibration, which is a lecture/lab course, formally in the fall of 2006 and until this project, did not have ‘hands-on’ activities beyond a ‘Helmhotz resonator project’ and an industrial visit. Common to universities nationwide and worldwide, severe budget cuts limited the development of additional hands-on activities and experiments crucial to a thorough practical understanding of vibration and noise analysis.

Three years ago the author developed two vibration related hands-on activities, the Helmholtz resonator project and an industrial visit. A Helmholtz resonator, which can be modeled as a spring-mass system, consists of a body (cavity) and a neck whose dimensions can be selected to tune the resonator to respond at a desired natural frequency. Student teams are required to design, build and test Helmholtz resonators, and write a formal report. [1] They are also required to visit a local industry and observe dynamic balancing of multi-disk shafts that are used to produce corn flour for cattle feed.

The author pursued other venues in an effort to develop a few tabletop vibration experiments for the Vibration course. A local automotive muffler manufacturing company donated a shaker and a pair of accelerometers. We were unable to develop any laboratory experiments with these donated items as the shaker was too bulky to move to and from storage and the accelerometers did not function properly. The author was able to identify Daryl White, an MET senior/advisee who owned a vibration measurement related business. White wanted to pursue his MET studies full time and therefore, donated several items to the University including a sound and vibration analyzer, a digital sound level meter, a microphone preamp, two microphones, an accelerometer, cables and connectors for use in our Vibration course. The author wanted to best utilize the White’s work experience and therefore, persuaded him to develop several table top experiments for the Vibration course utilizing the donated items. In consultation with the author he developed five experiments that can be run in a classroom or lab, and received credit towards his capstone project. White, who is also the coauthor of this paper, is currently pursuing his Master of Science Engineering Technology degree in our department and has subsequently been available to help the students in the lab in conducting the experiments.

Vibration Experiments:

In summer, 2011, five vibration experiments were initially developed by the coauthor and the author utilizing the donated equipment a few of which are shown in Figs. 1-6. In the first experiment, the students familiarize themselves with the instrumentation and the frequency analysis freeware, Audacity. In the second experiment they learn to record time domain data and perform frequency analysis. In the third experiment they learn to use the accelerometer in vibration measurements. In the fourth experiment the students learn to perform noise analysis of an internal combustion engine exhaust system. In the fifth experiment they learn to perform spectrum analysis for different noise and vibration signals. Information pertaining to the above-mentioned five labs was obtained in part from references 2 and 3. As this was our first time with the vibration experiments and due to the time and space constraints our students could conduct experiments 1, 2 and 3. Also, the sound and vibration analyzer (Fig. 1) developed a technical problem and stopped working after the third experiment.

Fig. 1. Gen Rad 1564 Sound and Vibration Analyzer.

Fig. 2. Radio Shack 33-2055 Digital Sound Level Meter.

Fig. 3. Microphone/Preamp Battery Power Supply.

Fig. 4. Endevco 2219E Accelerometer.

Fig. 5. GenRad 1560-P42 Preamp.

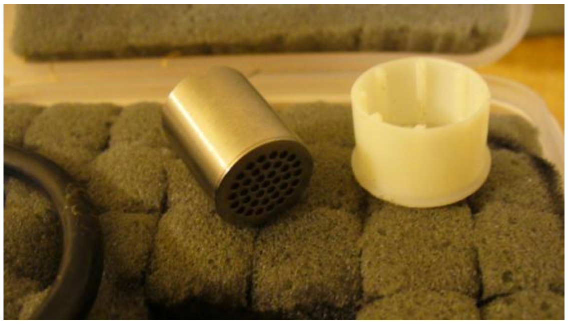


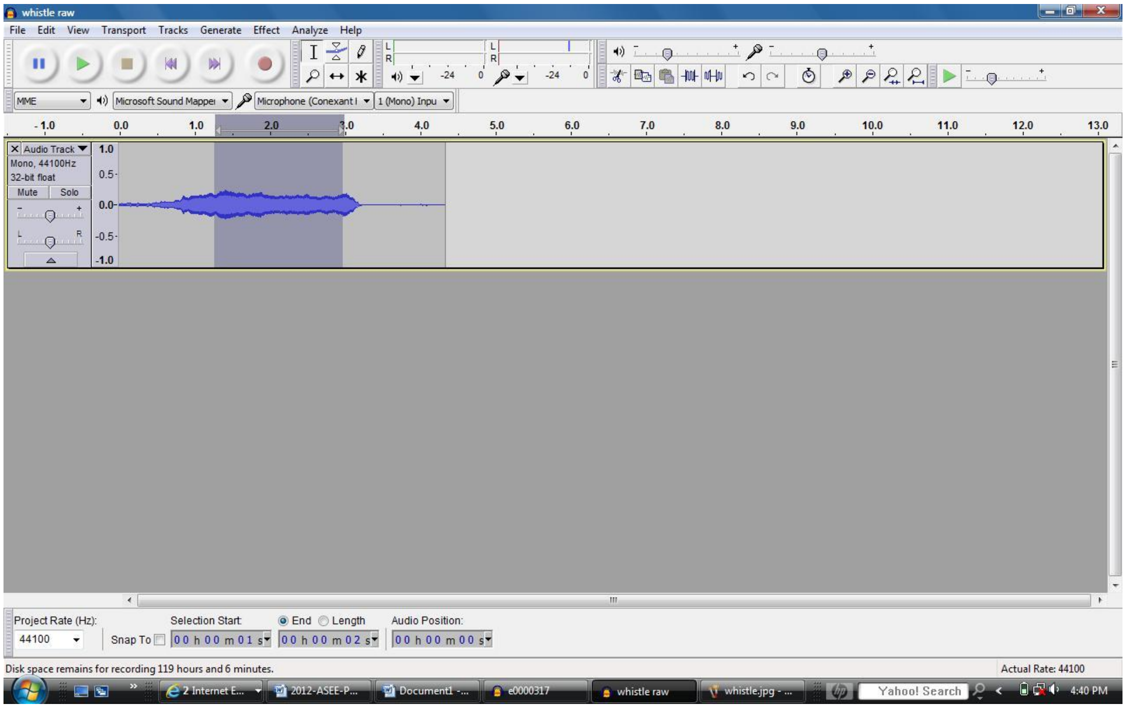
Fig.6. GenRad 1962, ½-inch microphone.

The first lab exercise, “Familiarity with Audacity and recording instrumentation” utilized the following equipment:

- Microphone power supply with fresh batteries
- Three-pin power supply to preamp cable
- GenRad 1560-P42 preamp
- GR 1962, ½-inch microphone
- BNC to mini stereo cable

The procedure of the exercise was as follows:

1. Attach cables to the microphone, battery power supply and plug the mini stereo output into the microphone input of the computer.
2. Run the Audacity software on the PC or laptop computer and under Preferences, set the input recording device to ‘microphone’.
3. While whistling a constant tone, press the Record button on the Audacity screen and after several seconds stop recording.
4. Using the Selection tool, delete the unwanted portions of the recording at the beginning and end (Fig. 7) so that the student is left with a decent clean sound.



Project Rate (Hz): 44100

Snap To ☐

Selection Start: 00 h 00 m 01 s

● End ○ Length 00 h 00 m 02 s

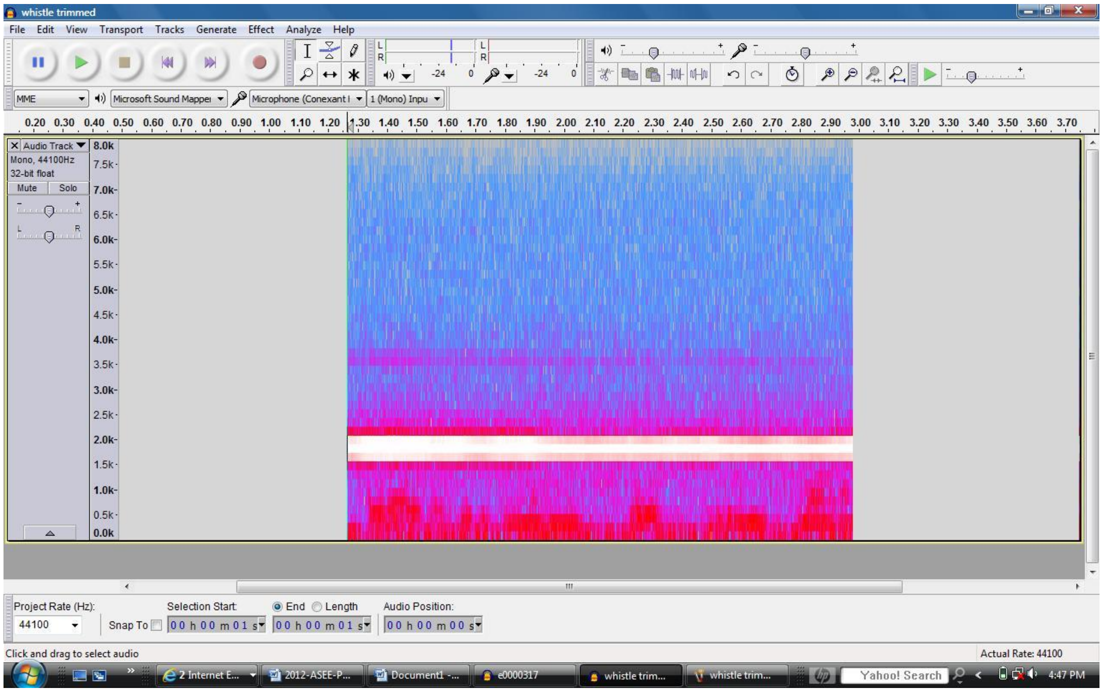
Audio Position: 00 h 00 m 00 s

Disk space remains for recording 119 hours and 6 minutes.

Actual Rate: 44100

Fig. 7. Time domain data obtained for a constant tone whistle using Audacity.

5. On the left side click Audio Track, then Spectrum. This displays a visual representation of the spectrum of the sound (Fig. 8). The student should see a predominant area that is highlighted. Zooming in will increase the clarity.



Project Rate (Hz): 44100

Snap To ☐

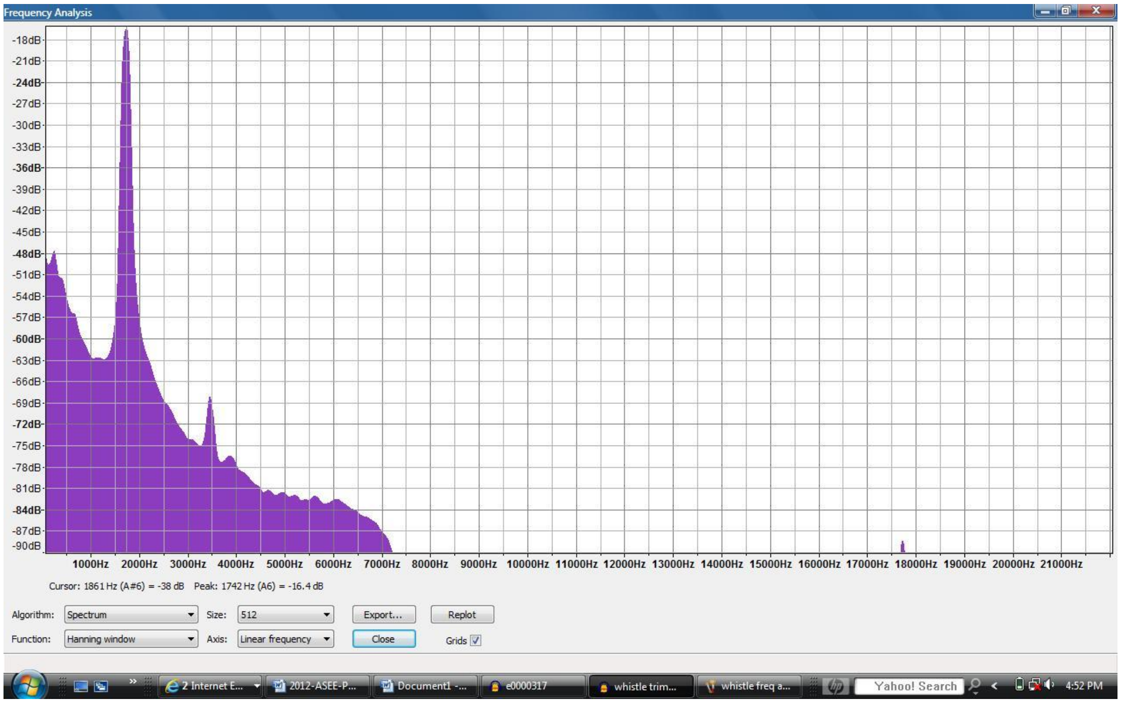
Selection Start: 00 h 00 m 01 s

● End ○ Length: 00 h 00 m 01 s

Audio Position: 00 h 00 m 00 s

Fig. 8. Spectrum obtained for the time domain data of Fig. 7.

6. Click on audio track again and select waveform. This should bring the student back to the original view shown in Fig. 7.
7. Under the Analyze Feature, use Plot Spectrum.

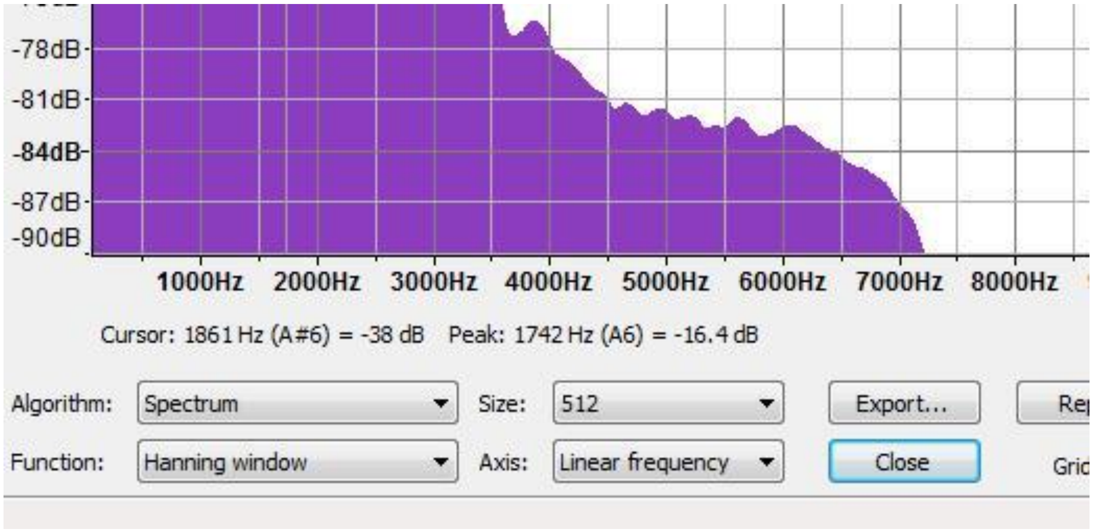


Cursor: 1861 Hz (A#6) = -38 dB Peak: 1742 Hz (A6) = -16.4 dB

Algorithm: Spectrum
Size: 512
Function: Hanning window
Axis: Linear frequency

Fig. 9. Plot of the spectrum for the time domain data of Fig. 7.

8. The student should see an analysis of the whistle with a spike at the predominant frequency of the whistle (Fig. 9). At the bottom of the graph, it will state the peak frequency at the maximum decibel level (Fig. 10) . The student should record this number.

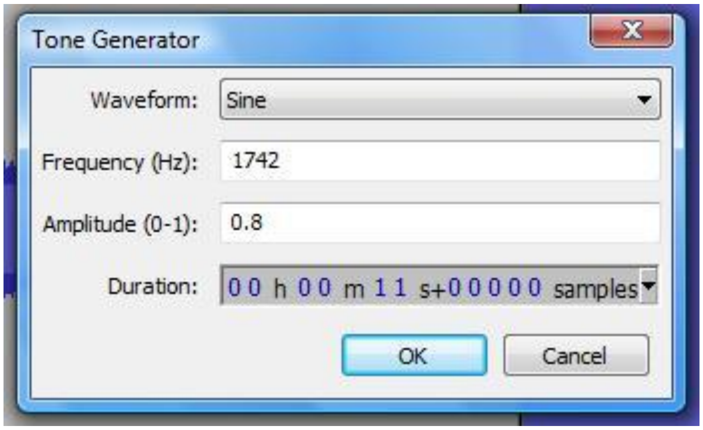


Cursor: 1861 Hz (A#6) = -38 dB Peak: 1742 Hz (A6) = -16.4 dB

Algorithm: Spectrum
Size: 512
Function: Hanning window
Axis: Linear frequency

Fig. 10. Close up view of the bottom portion of Fig. 9.

9. Close the Analysis window. Choose “Generate” “Tone” and input the frequency (the number recorded in Step 8) of the whistle (Fig. 11).



Waveform: Sine

Frequency (Hz): 1742

Amplitude (0-1): 0.8

Duration: 00 h 00 m 11 s+00000 samples

Fig. 11. The tone generator feature of Audacity.

10. Using the time shift tool (left and right arrows at the top of the screen), move the generated tone to the end of the recorded whistle tone.

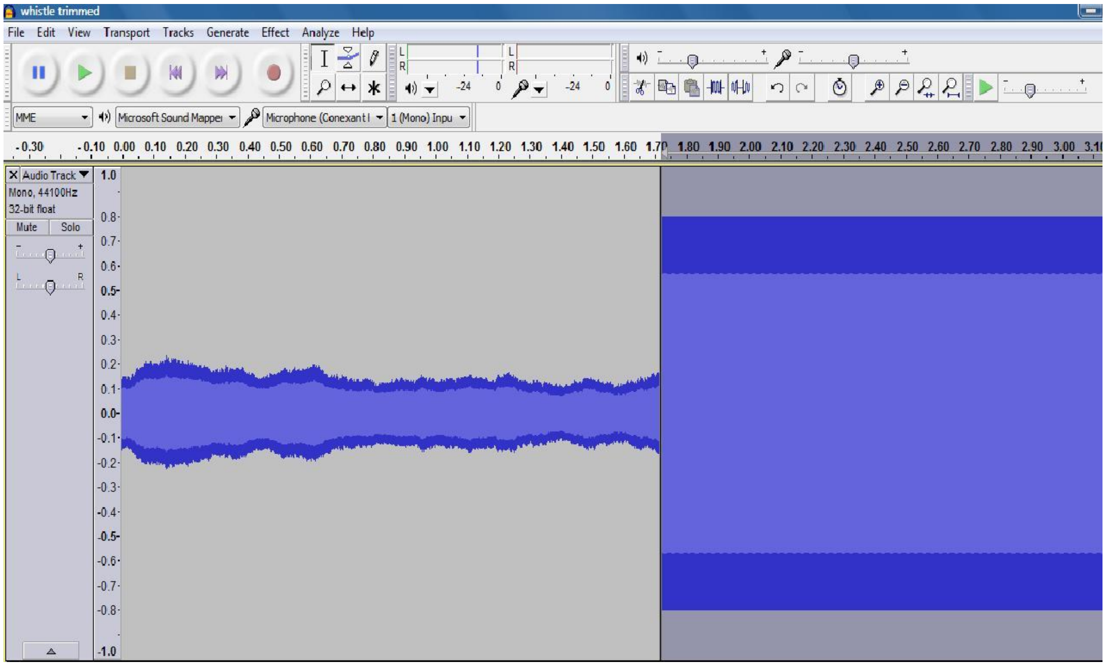


Fig. 12. The recorded whistle tone and the generated sound adjacent to one another.

11. Move the cursor to the beginning of the track and hit play. It should play the whistle then the generated tone of the dominant frequency. The student should determine if the whistle and the generated tone sound alike.

12. This lab exercise should leave the student with a basic understanding of the use of the Audacity software including basic spectrum analysis and frequency generation.

The second lab exercise, “Analyzing frequency and pressure” utilized the following equipment:

- GenRad 1560-P42 preamp
- GR 1962, ½” microphone
- GenRad 1564A Sound and Vibration Analyzer
- Computer with Audacity

The procedure of the exercise was as follows:

1. Attach the microphone to the preamp and plug the preamp into the Sound and Vibration Analyzer (SVA). The bottom left switch on the SVA’s front panel should be off (Fig. 14). Band Level dials should be turned so that the two matching white dots are pointed at 12 o’clock. The bandwidth dial should be set to ‘All Pass’.

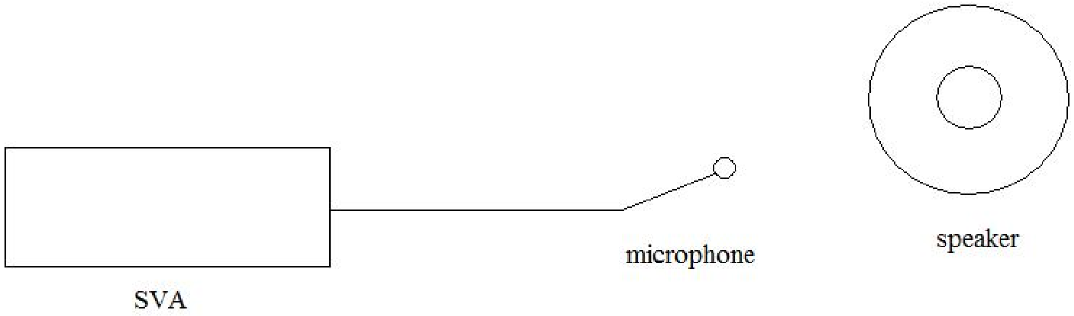


Fig. 13. Schematic diagram of the second lab exercise.

2. Using the tone generator feature of Audacity, generate a tone for a time period of approximately 120 seconds. Record the frequency of the tone.

3. The student will conduct a Sound Pressure Analysis.

   Turn the SVA on to the ‘Slow’ setting and allow several seconds for the equipment to stabilize. Play the generated tone. With the microphone placed at a fixed distance from the speaker, adjust the band level until the decibel (dB) needle reads somewhere in the middle of the gauge. The decibel reading is the algebraic sum of the band level plus the gauge reading, i.e. 80 + 3 = 83 dB. Record the dB reading.

   Sound pressure level, L_p, increases and decreases logarithmically. The generally accepted minimum sound that a human can discern is approximately 20 µPa at 1000 Hz and that level has been standardized as the nominal hearing threshold with a value of 0 dB. On the other end of the spectrum, the threshold of pain occurs at a sound pressure of approximately 100 Pa, a ratio of more than 1 million to 1. It is then clear that zero decibels do not indicate that there is no noise; it merely implies that it is equal to the reference level.

   Sound pressure level, L_p in units dB, is determined as follows.

$L_p = 10 \log_{10} (p/p_0)^2 = 20 \log_{10} (p/p_0)$

Where p_0 is typically 20 μPa

The student should determine the sound pressure level of the generated tone from the recorded dB value and p_0.

4. The student will conduct a Frequency Analysis

   Move the Bandwidth dial to 1/10 octave. The dB reading may decrease as the frequencies other than the primary frequencies are filtered. Adjust the frequency dial and frequency multiplier until a maximum dB reading is reached. Record the frequency reading. The student should determine if it matches the frequency generated by the tone generator.

Fig. 14. Close up view of the SVA’s front panel.

The third lab exercise, “Accelerometer use”, used the following equipment:

- Endevco 2219E Accelerometer
- Mini coax to BNC cable
- BNC extension cables as necessary
- Oscilloscope

The procedure of the exercise was as follows:

1. Attach the accelerometer to the cable and finally to the oscilloscope. Using the wax adhesive on the accelerometer, stick it to a running device, such as a refrigerator, humidifier or air compressor that is plugged into a wall socket and has a noticeable vibration to the touch.

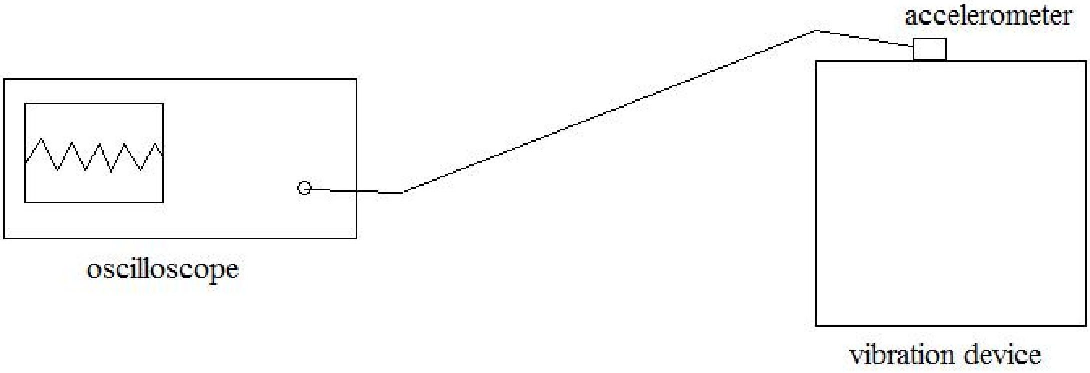


Fig. 15. Schematic diagram of the third lab exercise.

2. Turn on the oscilloscope and adjust the setting so that there is a decent waveform visible. This is the form of the forced harmonic motion in the object. Looking at the basic pattern and neglecting any 'bounce' that may occur at the top and bottom of the waveform, record the length of the period. Also record the average voltage of the waveform.
3. Determine the frequency of the forced harmonic motion.

   The accelerometer used produces 400 mV/G. Determine how many G's are produced by the forced harmonic motion.

   Looking at the waveform, the student should determine its best description. Is it a pure sinusoidal, a combination of sinusoidal waves, a square wave or non-periodic noise? The student should explain their answer. If there is a combination of waves, the student should determine the possible causes and solutions?

Conducting the Experiments:

In fall, 2011 we had twenty four students in the Vibration course and they were the first to run the vibration experiments. Currently, there is not a designated lab space for this course and therefore, the experiments were conducted in the ET department's rapid prototyping lab. Instructions for each experiment were made available to the students well in advance. They learned how to download the Audacity software and run the experiments following the steps and record the data. The students were not required to write a report this academic year. However, during the experiments they were asked to explain what they learned. A single-cylinder reciprocating engine (Fig. 16) which would fit in a 1 ft. X 1 ft. X 1 ft. box was used as the noise and vibration source. The students seemed to enjoy the lab activities and the following photographs show the experimental set up and the students.

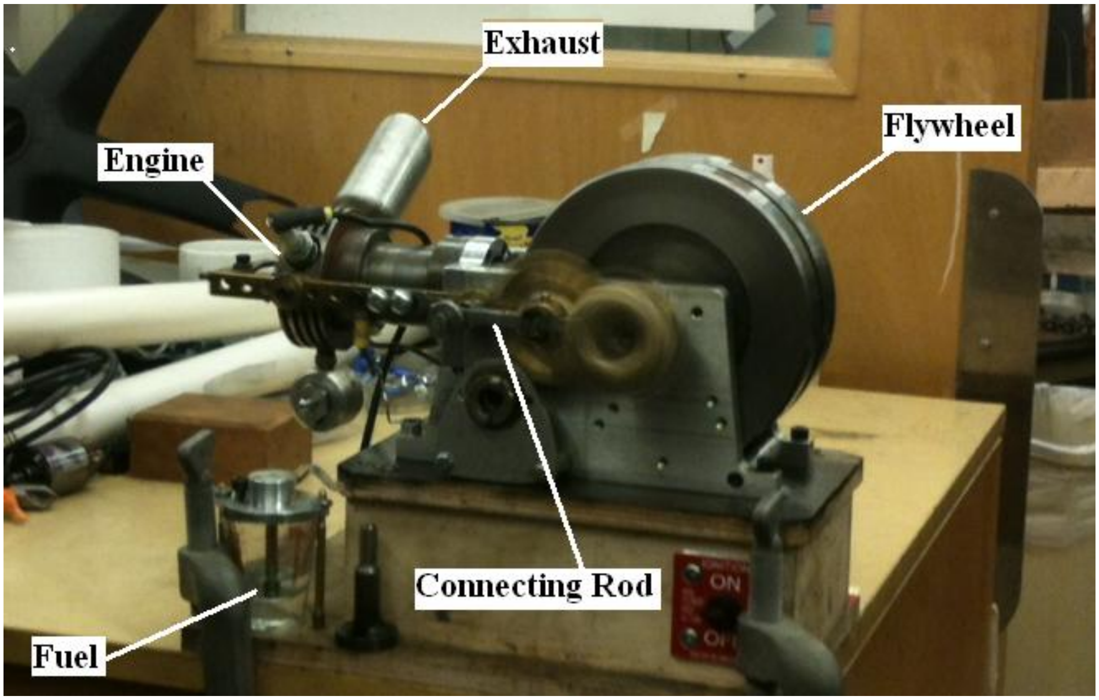


Fig. 16. The single-cylinder reciprocating engine used as a noise and vibration source

Fig. 17. Group discussion on the experimental results.

Course Objectives and Student Learning Outcomes Related to the Hands-On Activities:

In the fall of 2006 we prepared the objectives and learning outcomes for all MET courses as part of our preparation for the ABET accreditation. We included the following objectives in the ET 4830 – Vibration syllabus.

a. Oscillatory Motion: Students learn the basics of oscillatory motion such as simple harmonic motion and periodic motion, and vibration terminology.
b. Free Vibration: Students study the basics of free vibration. They calculate natural frequencies of spring-mass systems using the equations of motion, energy method, and principle of virtual work. They study the free vibration of viscously damped spring-mass-damper systems and learn to calculate the natural frequency using the equations of motion and the logarithmic decrement method.
c. Harmonically Excited Vibration: Students learn to formulate the equation of motion for a spring-mass-damper system subjected to forced harmonic vibration. They calculate amplitude and phase of oscillation and obtain complex frequency response. They learn the basics of rotating unbalance, support motion and vibration isolation. They study the working principles of vibration-measuring instruments such as seismometers and accelerometers.
d. Systems with Two or More Degrees of Freedom: Students study vibration of multi-degree-of-freedom systems with emphasis on the normal mode analysis, initial conditions and coordinate coupling. They learn to formulate the coupled equations of motion and represent in the matrix form for translational and rotational systems, and coupled pendulums. They learn to calculate eigenvalues and eigenvectors for different spring-mass systems. They learn the basics of forced harmonic vibration of multi-degree of freedom systems.
e. Vibration Measurements: Students learn about instrumentation and control related to mechanical vibration

We developed twelve learning outcomes for our MET concentration based on the ABET a-k criteria. As has been done at several U.S. universities, we use the tests, final exam, homework and laboratory activities as direct methods to evaluate the learning outcomes. The major field test (MFT), exit interview (oral and anonymous questionnaire) and employer and/or employee survey are used as the indirect methods to evaluate the learning outcomes. In the Vibration class the author gives two tests and one final exam, and they carry 65% of the final grade. The vibration experiments discussed in this paper, the Helmholtz resonator project and the industrial visit carry 35% of the final grade. The ET 4830 is a three credit-hour course with two credit-hours of lecture and one-credit hour (three contact hours) of lab. The hands-on activities address the course objectives *a*, *b* and *e* listed above. We use these, in addition to the tests and the final exam, to evaluate the following learning outcomes.

- An ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes.
- An ability to function effectively as a member or leader on a technical team.
- An ability to identify, analyze, and solve broadly-defined engineering technology problems;

In our anonymous exit interview questionnaire for the graduating seniors some students have complemented the Helmholtz resonator project as a very useful hands-on activity. We have to wait until May, 2012 to get the official feedback from the graduating MET seniors on the vibration experiments. We started teaching Vibration in the fall of 2006 but the MET major field test (MFT) was developed in early 2005. Therefore, we could not add questions from Vibration later as we could annually modify/replace only five percent of the MFT questions mainly based on the students' feedback. We developed a brand new MFT for the 2010-11 academic year that includes questions from Vibration. The fall, 2010 MFT results indicated that less than 25% of the majors who took the test got the correct answer in the case of two vibration-related questions. Our analysis during the last fall showed that the two questions were very simple and the related topics are well covered in the class. The reason for missing the two questions could be due to the fact that some students take ET 4830 a few semesters before they take the MFT. It could be additionally attributed to those students having limited hands-on experience with vibration apparatus which help cement theoretical concepts based on real-world applications. Therefore, we decided to keep the two questions and provide some orientation to the MET majors before they take the MFT.

Conclusions:

The donated vibration/noise measuring devices are slightly old but they have served the purpose of running some basic vibration experiments. ET 4830 students learn the theory of vibration measuring instruments and rotational unbalance [4] in the class. The lab activities give the students an opportunity to use these instruments and better understand their applications. In the class they learn the working principle of an accelerometer and its response to a vibrating mechanical part (or support motion) as a function of the excitation frequency. In the lab they learn how to use an accelerometer and measure the amplitude and frequency of vibration. The students learn the principle of rotational unbalance due to an eccentric mass and the resulting rocking moment that can damage the bearings. During the industrial visit they understand how rotational unbalance in a multi-rotor shaft is diagnosed and corrected using sophisticated sensors. The resonator project gives the students an opportunity to design, build and test a spring-mass system, and compare the theoretical and experimental results. The hands-on activities discussed in this paper also promote team work among the students.

Some of the equipment for the experiments, such as an oscilloscope and a laptop computer are easily procured from other departments, though it would be ideal to maintain a full complement of test equipment specifically for the Vibration experiments and exercises. An extended goal for the next two years is to develop at least two more vibration-specific experiments and find a permanent location for the lab. The student response was good for the three experiments that are discussed in this paper and overall the students were able to use the experiments to better grasp the theories discussed in the lecture portions of the class. We hope to formalize the lab activities and require the students to write a formal report in fall, 2012. Additionally, we intend to include lab-related question(s) in our MFT during our annual revision in May of 2013.

In the 2010-11 academic year we did not have a formal way of assessing the students' learning related to the lab activities. They were evaluated based on the participation and ability to answer questions during the lab sessions. As mentioned before our ET 4830 students worked on the

Helmholtz resonator project in 2010 fall, and in 2011 fall they completed three lab experiments in addition to working on the resonator project. A brief analysis of the normalized student scores for these two cases indicates the mean scores are 94 and 90, and the median scores are 95 and 97, respectively. In 2011 fall a few students missed two lab activities and their scores have contributed to the lower mean. As we know the median is a more dependable measure of the central tendency in cases such as the student scores. Our present analysis should be considered as the first step towards assessing the lab-related student learning and not be construed as conclusive because there is not a significant difference between the median scores. We hope to have more formalized lab activities and better student assessment instruments by 2012 fall.

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