Early Development of an Energy Density Probe Calibrator

Scott R. Woolston
Department of Mechanical Engineering
Brigham Young University
435 CTB
Provo, UT 84604

ABSTRACT
BYU has recently developed an inexpensive energy density probe. It lacks, however, a simple effective broadband calibrator. The purpose of this research is to develop a simple calibrator, capable of calibrating all of the microphones on the energy density probe simultaneously over the frequencies 0 to 1 kHz.

INTRODUCTION
Traditionally in the field of acoustics, pressure has been the main acoustic quantity used in both theoretical and experimental work. Pressure can be readily measured using microphones. However, over the last several years, energy density (ED) has been used for an increasing number of applications. ED is a measure of the kinetic and potential energy in a sound field. One current drawback is the lack of an inexpensive, commercially available instrument for measuring ED. Brigham Young University has recently developed an inexpensive ED probe that could be commercially viable. However, the probe lacks an effective calibration method.

Calibration is the process of relating the output of a transducer to the quantity it is measuring. For example, when calibrating a microphone, the microphone is exposed to a known pressure and the voltage output is measured. This yields a calibration constant in units of pressure over voltage. This calibration constant can then be used to obtain pressure from voltage making measurements. High end microphones have a flat response over all frequencies and only need to be calibrated at one frequency. However, inexpensive microphones do not respond the same at every frequency and must be calibrated at each frequency in the band of interest.

The ED probes developed at BYU consist of inexpensive electret microphones embedded on the surface of a sphere. An example of one of the probes can be seen in figure 1.

Figure 1: BYU ED Probe
Early attempts at calibrating the probe consisted of calibrating each of the microphones individually. This caused repeatability issues because the probe had to be removed from the calibrator between each microphone. This was a slow and tedious process that did not yield accurate results.

The purpose of this research was to develop a calibrator capable of calibrating all of the microphones simultaneously over the frequency range 0 to 1 kHz.

**Calibrator Design**

The goal was to develop a calibrator that could calibrate the entire probe at one time. A small cavity was designed on the assumption of a lumped element model. This assumption can be made when the characteristic dimension of the cavity is small compared to a wavelength. The lumped element model removes all spatial effects from the model and states that the pressure will be uniform throughout the cavity. It is essential that this assumption be valid or else all of the microphones on the probe will see different pressures and it will not be possible to calibrate them all at once.

It is generally accepted that this assumption is safe to make when

\[ ka < 0.1 \]

where \( k \) is the acoustic wavenumber defined by

\[ k = \frac{\omega}{c} \]

where \( \omega \) is the frequency of interest and \( c \) is the speed of sound. Also, \( a \) is the characteristic length of the cavity. This indicates that the cavity should be as small as possible to ensure the validity of the lumped element assumption.

However, in the design of the cavity, the size was limited by the size of the probe. The chosen design had a cavity that was a cube with sides 0.061 m. Table 1 shows \( ka \) at various frequencies over the range 0 to 1 kHz.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>( ka )</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>0.28</td>
</tr>
<tr>
<td>500</td>
<td>0.56</td>
</tr>
<tr>
<td>750</td>
<td>0.84</td>
</tr>
<tr>
<td>1000</td>
<td>1.12</td>
</tr>
</tbody>
</table>

*Table 1: \( ka \) Between 0 and 1 kHz*

It is immediately evident the lumped element assumption is being violated. However it is not evident how much variation this will introduce into the pressure field. As long as the variation in pressure between microphone positions is less than 0.5 dB, the calibration will be acceptable.

Figure 2 shows the design of the calibrator. The probe is enclosed inside the cavity. The speaker mounted to the side creates the pressure field inside the cavity. A calibrated microphone is also exposed to the pressure field.
Calibrator Testing

The goal of the testing was to determine the uniformity of the pressure field around the probe. This was done by measuring the pressure from one of the microphones on the probe. The microphone was faced toward the speaker and the speaker was driven at a specific frequency and amplitude. Without opening the calibrator, the probe was rotated 15 degrees and the pressure was again measured. This process was repeated until the pressure around the entire probe had been measured. The pressure change from the first position in decibels was plotted as a function of frequency. Figure 3 shows the results at 250 Hz.

At 250 Hz, the pressure variation is less than the target of .5 dB variation. However, these results are not repeated at the higher frequencies. At 500 Hz, the maximum variation is more than 2 dB and is more than 12 dB at 1 kHz. These results are shown in figures 4 and 5 respectively.

As discussed previously, the conditions necessary for the lumped element model had been violated. The results at 250 Hz were promising, so it was thought that making the cavity smaller would improve the results at other frequencies.

This was accomplished by machining a closed-cell foam insert that would fill in the empty space
around the probe, effectively reducing the dimensions of the cavity. Holes were left for the speaker and the reference microphone. The insert can be seen in figure 6.

Figure 6: Foam Insert

Figure 7 illustrates how the inserts fits into the calibrator

Figure 7: Insert with Calibrator

The insert was tested following the same procedure as described previously. At 250 Hz there was virtually no change in the result. At 500 Hz the variation almost doubled to more than 4 dB. At 1 kHz the error dropped from 12 dB to less than 8 dB.

It was thought that further improvement could be gained by breaking up the space around the circumference of the sphere as standing waves could be forming around the sphere. A new insert was designed with ridges. The ridges were designed in such a way that there was no single path all the way around the probe. There were small openings, however, that allowed the pressure from the speaker to reach each microphone. The insert is shown in figure 8.

Figure 8: Foam Insert with Ridges

The testing procedure was repeated with the new insert at 500 and 1000 Hz. The results are shown in figures 9 and 10 respectively.

Figure 9: Pressure Variation at 500 Hz

Pressure Variation (500 Hz with insert #2)

Figure 10: Pressure Variation at 1000 Hz
An inspection of the figures reveals that the variation in the pressure was made worse at 500 Hz and improved at 1 kHz. However, neither of them fall below the desired .5 dB.

**Conclusion**

The early stages of the calibrator design reveal that a different approach must be taken. The probe itself is just too large to validate the use of the lumped element model. While acceptable results were achieved at 250 Hz and below, this was not the original goal. The calibrator must be able to calibrate up to 1 kHz while keeping the variation around the probe less than .5 dB. A new design that does not rely on lumped element acoustics must be developed.

---

**References**