FEATURE *My Favorite Experiment Series by R.M. French*

NEW SERIES

A POP BOTTLE AS A HELMHOLZ RESONATOR

The Helmholz resonator is perhaps the simplest acoustic resonant system. The ideal Helmholz resonator consists of an air volume enclosed with rigid walls and vented through a neck whose cross-sectional area is small compared to the dimensions of the volume (see Figure 1). It is assumed that the air volume acts as a mechanical spring and the air in the neck acts as a moving mass. The expression for the natural frequency of the system is[1]

$$f = \frac{c}{2\pi}\sqrt{\frac{A}{tV}} \quad (1)$$

Where c is the speed of sound,[2] A is the cross-sectional area of the port, t is the length of the neck and V is the volume. A familiar approximation to the ideal resonator is a 20 oz plastic pop bottle. Blowing over the top of the bottle makes a whistle whose frequency should be described by this expression.

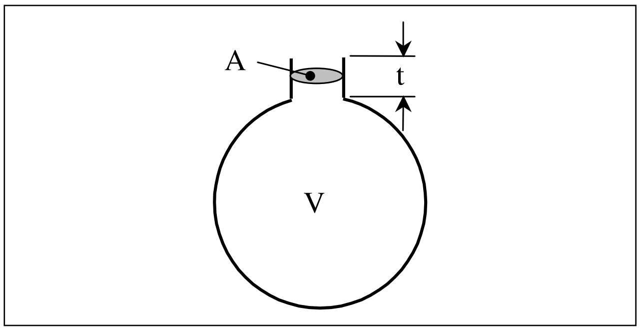

Fig. 1: Ideal Helmholz resonator

EXPERIMENT

As an experiment, the frequency of the sound made by blowing over the top of a bottle was measured with different liquid levels in the bottle. Figure 2 shows the bottle with the label removed and marks showing the different fill levels. The frequencies and corresponding air volumes are shown in Table 1. The measured acoustic resonance frequencies from the different fluid levels can be used to identify unknown terms in Equation 1 using a least squares approach.

Table 1—Experimental results

CONDITION	AIR VOLUME (Liters)	FREQUENCY (Hz)
1	0.195	330.0
2	0.296	260.3
3	0.411	220.1
4 (Empty)	0.616	175.9

The volume of the enclosed air was determined by weighing the bottle empty and filled with water. By subtracting the empty weight (tare weight), the weight of the water filling the bottle is found. The density of water is assumed to be 1 gm/cm^3. By weighing the bottle at the different fill levels, it is a simple task to find the resulting air volumes.

The sound recordings clearly showed the resonant frequencies and several harmonics for each fill level as seen in Fig. 3.

Equation 1 assumes an ideal system that isn't completely realized in the pop bottle, so at least one of the parameters must be tuned using experimental data. The neck of the bottle is approximately 21.5 mm in diameter, giving a cross-sectional area, A, of 363 mm^2. If all parameters except t are assigned, t can be selected to give the best correlation

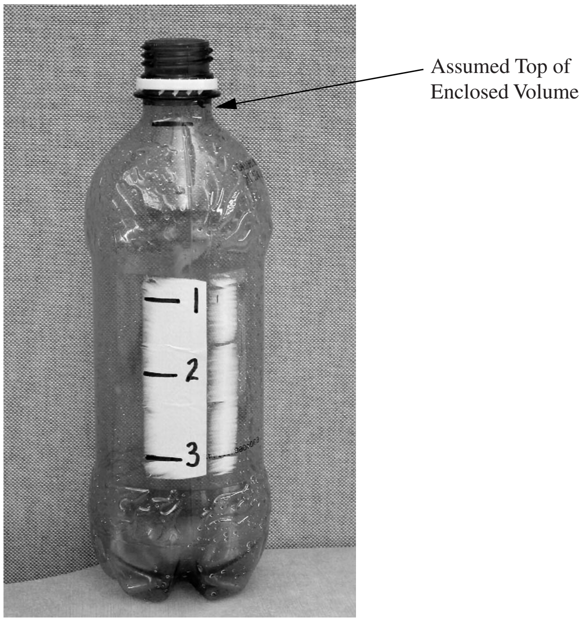

Fig. 2: Bottle used for experimental data

Editor's Note: *ET is creating a new feature series to focus on short, educational/teaching related articles under the title "My Favorite Experiment." The short articles demonstrate experimental techniques that can be applied directly to the classroom and laboratory to enhance both the teaching process and conveyance of various apparatus and measurement methods to the students.*

This month, we are featuring an article titled "A Pop Bottle as a Helmholz Resonator" by Prof. Mark French (SEM Member) of Purdue University, West Lafayette, IN, formerly with Robert Bosch Corporation. Series Editor: Kristin B. Zimmerman, General Motors Corporation.

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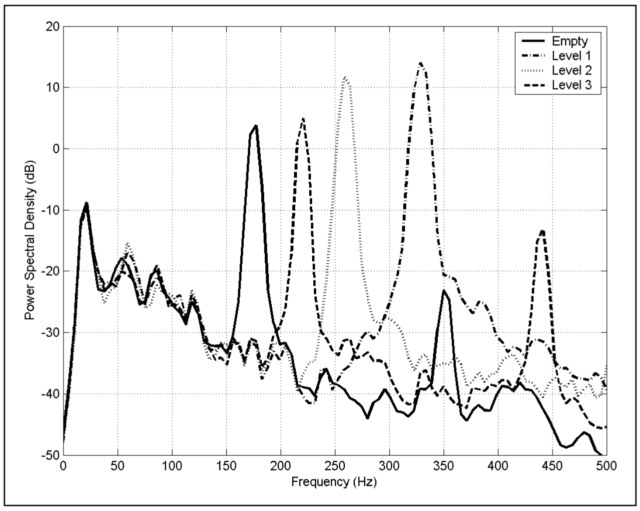

Fig. 3: Frequency domain representation of sound data

between measured and calculated frequencies. The assigned values are: $A = 363$ mm^2, $c = 338.3$ m/sec and volumes as shown in Table 1. A value of $t = 52$ mm minimized the squared error function for measured and calculated frequencies as defined in Eq. 2. The results are shown in Table 2.

$$E = \sum_{i=1}^{4} (f_i^{\exp} - f_i^{calc})^2 \quad (2)$$

SUMMARY

The Helmholz resonator is both a simple introduction to acoustic resonance and a useful model of many physical systems. These include such diverse examples as engine intake manifolds and the bodies of stringed musical instruments. A pop bottle with a roughly cylindrical body and a short cylindrical neck is a good example since it is readily available and its acoustic response is intuitively familiar. Using several different fluid levels to vary the enclosed air volume, the parameters in the Helmholz equation can be identified so that the calculated frequencies are within a few percent of the measured ones.

Table 2—Calculated and measured resonant frequencies

CONDITION	MEASURED FREQUENCY, f_i^{exp} (Hz)	CALCULATED FREQUENCY, f_i^{calc} (Hz)	% DIFFERENCE
1	330.0	321.8	−2.48
2	260.3	261.5	0.46
3	220.1	221.9	0.82
4 (empty)	175.9	181.2	3.01

References

1. Rossing, T.D. "The Science of Sound, 2nd Edition", Addison-Wesley, 1990.

2. Anderson, J.D. "Introduction to Flight", McGraw-Hill, 1978. ■

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