

# Boys Town National Research Hospital

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## **Stepper: Thévenin-Equivalent Source Determination**

### **Abstract**

*Stepper* is a program for determining Thévenin-equivalent sound-source characteristics. This program delivers a stimulus into a cylindrical cavity and measures the pressure. The cavity length is varied by moving a piston to specified positions. Following a series of measurements, the Thévenin-equivalent source impedance and source pressure are written to a file. In addition, *Stepper* reports a set of quality metrics that indicate whether the system is performing up to expectations. The current version of the software (1.2.0.0) has been adapted to work with the ER10X probe microphone system from Etymotic Research.

09 November 2016

# Stepper Procedure

## Introduction

Calibrating stimuli using Forward Pressure Level (FPL) or Sound Intensity Level (SIL) requires that the Thévenin-equivalent impedance and pressure of the sound source be determined from a set of known acoustic loads. Typically, estimation of Thévenin-equivalent source characteristics (acoustic pressure and impedance) requires measurements in a set of cylindrical cavities of known lengths. The length of the tubes determines where the frequency resonant peak occurs. A stimulus is presented in sound pressure level to the cylindrical tubes to obtain measurements. The stepper controller application described below provides a way to calibrate the sound source for FPL or SIL measurements and reports several quality metrics. In automatic mode, the stepper controller application digitally positions a piston inside a stepper motor box that mimics different cavity lengths. It can also be used to calibrate sound sources using a set of different length physical cavities. The stepper program can be launched by double-clicking “Stepper Sigpro” icon on the desktop. The stepper software can also be launched from EMAV, SYSRES and CREFL. It allows testing up to 8 cavities (resonant frequencies) or stepper positions by inserting a probe microphone, with its proper foam or silicone tip, into the controller box and running the software described below.

## Installation Information:

The distribution files for the Stepper program are online at <http://audres.org/cel/thev/>. After downloading the “Windows Installation,” run “setup.exe” to perform the Installation.

## Stepper Procedure Overview:

1. Set the half-wave resonant frequencies that you wish to use for determination of Thévenin-source characteristics.
2. Stepper software finds the cavity lengths that will result in the specified resonant frequencies by iterating on the piston position and making pressure measurements at each position.
3. At each of these cavity lengths, Stepper presents a stimulus and makes a pressure measurement. Once pressure measurements for each cavity length have been completed, the Stepper calculates Thévenin-source characteristics. Separate output files are created for both the pressure measurements and the Thévenin-source characteristics.
4. The Stepper software reports several quality metrics that indicate reliability of the Thévenin-source determination.

## Preliminary steps

In addition to an ER-10X probe microphone system (from Etymotic Research), Stepper requires an audio device. Stepper expects to have exclusive access to both devices, so all other audio programs and the ER10X controller

program should be closed. Best results have been obtained when using an ASIO driver for the audio device. The ER10X should be powered on prior to double-clicking “Stepper Sigpro” icon.

### Settings menu

The “Settings” drop-down menu has two options:

**Load Last Settings** – Brings up the default sound card for the system and loads the settings the stepper used in the last run. If it is the first time you are running it, it loads the default settings.

**Edit Settings** – Allows you to change *Calibration Variables* and *Stepper Motor Settings*.

1. **Calibration Variables** are as follows (see Figure 1):

- **Buffer Size** – the number of samples per channel in one sweep of the stimulus. Default = 8192
- **Stimulus Type** – the type of stimulus used for calibration. Choices are White Noise or Chirp. Default is Chirp.
- **Sampling Rate** – 8,000 to 200,000 Hz.
- **# of Sweeps** (for Auto Calibration) – The number of sweeps sets averaged in the auto calibration phase. The program presents several sweeps in each set, so the number of sweeps averaged will be a multiple of the specified number. The measurement is repeated for each of the two sound sources.
- **# of Sweeps** (for Find Positions) – The number of sweeps sets averaged in the find positions phase. The program presents several sweeps in each set, so the number of sweeps averaged will be a multiple of the specified number. The measurement is repeated for each of the two sound sources.
- **# of attempts** (for find positions) – The maximum number of times the program will iterate on cavity length in an attempt to get the specified resonant peak. The number selected should be a balance between accuracy and time. Default is 6.
- **# of Cavities** – 1 to 8 cavities. Default is 6.
- **Cavity Diameter** – Internal cavity diameter (in centimeters) used in the calculation of ideal cavity impedance.
- **Attenuation** – the number of dB that the calibration stimulus is attenuated relative to maximum output. Range is 0 to 100 dB; default is 20 dB. The optimal value of attenuation is a compromise between achieving a good signal-to-noise ratio and avoiding distortion due to producing a large microphone signal.

☐ **TIP** –When the output of Stepper (THS file) is used for FPL calibration of dpoae measures in EMAV, the attenuation used in EMAV should match the attenuation used in Stepper to create the THS file.

- **Microphone Sensitivity** – sensitivity of the microphone in volts per pascal, when it is assumed to be constant for all frequencies. The value of this parameter is determined by the hardware.

☐ **TIP** –The value of the microphone sensitivity of the ER10X is 0.5.

**Microphone Transfer (optional)** - The name of a file that specifies a frequency-dependent microphone sensitivity. The MP\_transfer file may be a text file with one frequency and sensitivity (V/Pa) pair on each line. In this case, the MP\_sensitivity parameter is still used to scale waveforms, but not frequency components levels. Alternatively, the MP\_transfer file may be a MATLAB-compatible SYSRES data file. In this case, the transfer function contained in the MAT file is multiplied by the MP\_sensitivity parameter.

- **Output options** – The program always creates a PRB file that contains cavity-pressure measurements. In addition, three other types of output files may be optionally created:
  - Create THS – creates THS file that contains Thévenin-equivalent source characteristics derived from a PRB file.
  - THL – contains Thévenin-equivalent load characteristics derived from a CAL file (real-ear or cavity) using a specified THS file.
  - Write Data - creates txt files with
    - Cavity pressure measurements (e.g., cav111.txt). These measurements are identical to those saved in the PRB file.
    - Thévenin-equivalent load pressure (e.g., pc01.txt) and impedance (e.g., zc01.txt) for each sound source and cavity. These measurements are identical to those saved in the THL file.
    - Thévenin-equivalent source pressure (ps01.txt and ps02.txt) and impedance (zs01.txt and zs02.txt) for each sound source. These measurements are identical to those saved in the THS file.
  - These txt files are useful for users who do not have access to MATLAB software.

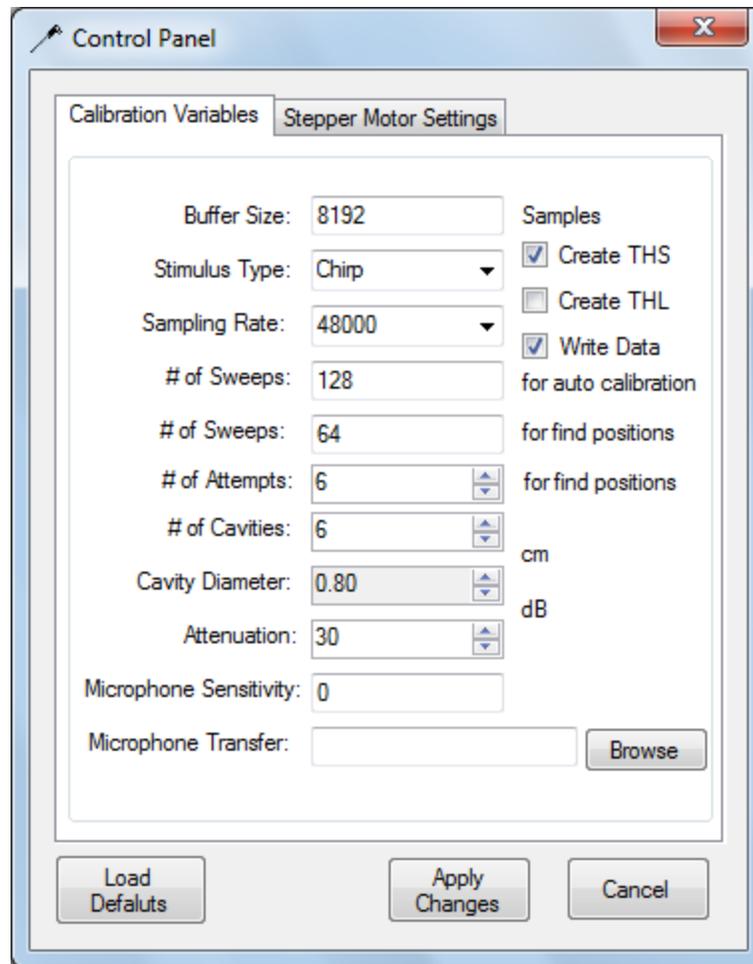


Figure 1. Calibration Variables Menu.

2. **Stepper Motor Settings** are as follows (see Figure 2):

- “Use Stepper Motor” checkbox – When selected, the stepper motor is used to calibrate. When box is unselected, the stepper motor is disengaged and physical cavities can be used to calibrate.
- “Position” – specifies piston locations using stepper motor position. The program calculates the resonant peak from the position number and displays it on the main page. Note: stepper motor positions are dimensionless.
- “Frequency” – specifies piston location by frequency of the resonant peak. The positions required to produce the specified resonant peaks are displayed on the main page.

To edit stepper piston positions, enter values from lowest to highest frequency or larger to smaller position numbers. Options for editing positions are to the right of the field.

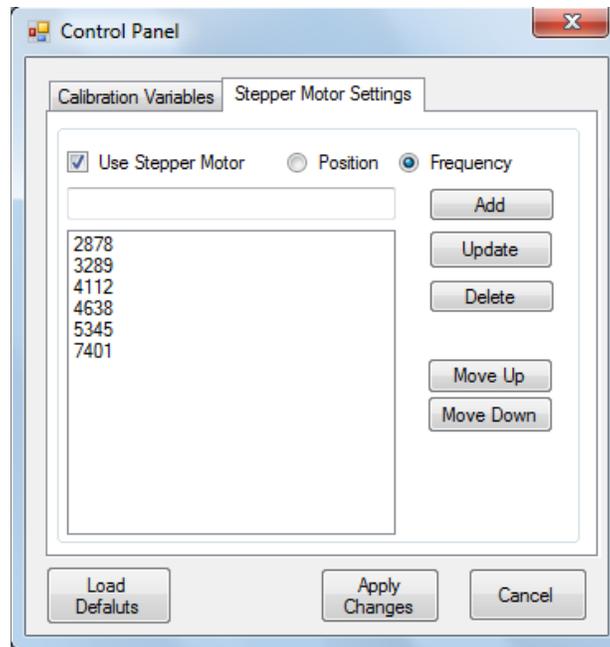


Figure 2. Stepper Motor Settings menu.

3. Additional Settings on the main screen (see figure 3).
  - Sound Card – Drop down menu automatically populated by the program. Sound devices that are turned off or disabled will not appear on the list.
  - ☞ **TIP** – Under Windows Control Panel, Sound option, make sure that the default sound playback device matches the default sound recording device.
  - “Set Frequency Precision” – on the main screen under “Find Positions” (see Figure 3, default is 10 Hz)- This specifies the acceptable difference between the measured and target frequency (of the half-wave resonant peak) when finding the piston position. The number of times the program will attempt to adjust the piston to achieve the resonant frequency is influenced by the number in the “Set Frequency Precision” and the “# of attempts” in the calibration variables setting.

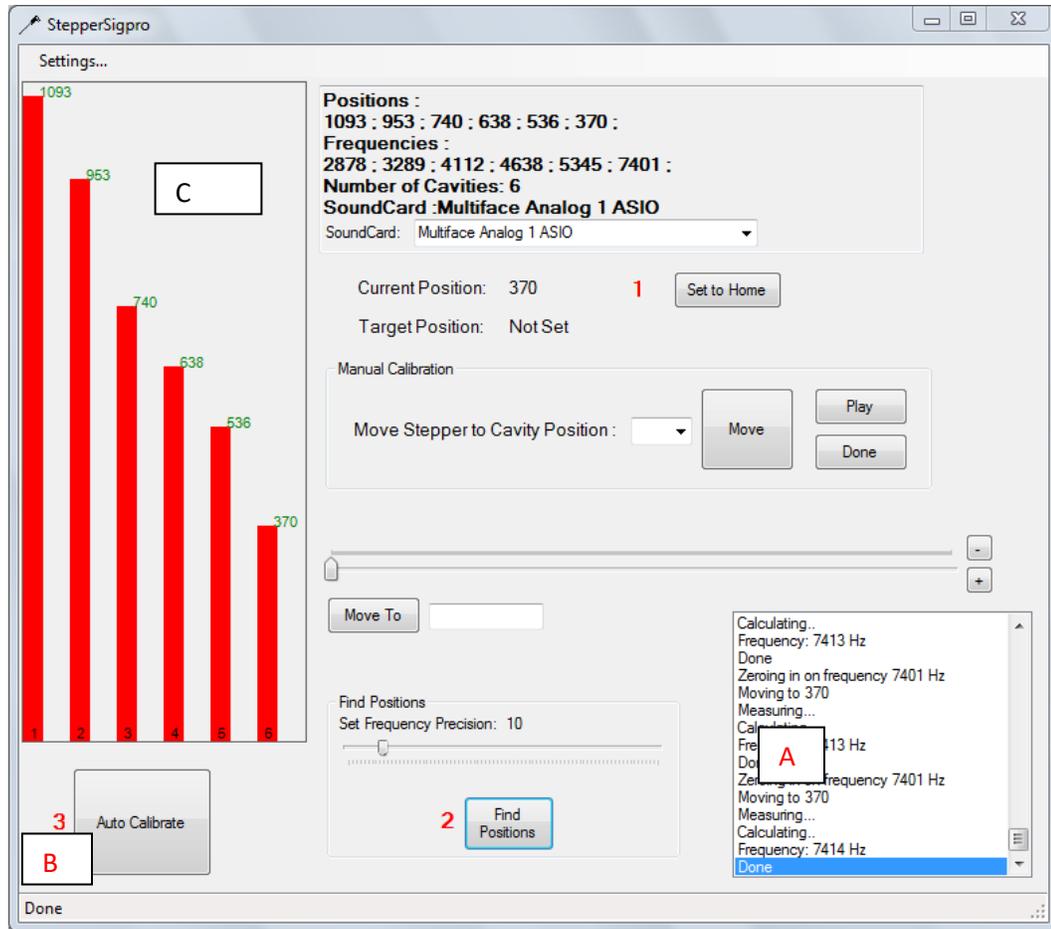


Figure 3. Completed stepper motor search to determine the position needed to produce a resonant peak at each frequency listed. The piston positions and the frequencies of the resonant peak specified in “settings” are displayed at the top center of the graphic. Higher position numbers reflect greater cavity length. Location C on the left indicates piston positions with a visual graphic of cavity length. This visual graphic is updated after the “find positions” function has been run. The List Box in the lower right corner of the screen will display the automated steps in order as the Stepper Motor goes through the calibration sequence (location A). Current position is the piston position that corresponds to the current cavity length. Target Position should be 0 for the automated calibration method. It reflects the number of the first cavity (numbers range from 0-7). The text under location B indicates the current status of the program.

### **Thévenin Calibration using the automated method:**

There are 3 steps to the automated calibration procedure:

**Step 1.** “Set to Home” . This moves the piston to the ready position in preparation for Step 2.

**TIP** - “Current Position” should be 0. If it reads -1, move the piston to a different position by adjusting the slider position in the Manual Calibration section and then select “Set to Home” again. This should change the current position to 0. If you run the calibration when the current position is -1, the quality metrics will be unacceptable

**Step 2. “Find Positions”**. Stepper guides the motor to find the necessary positions that will produce resonant peaks at the frequencies specified in “Settings”.

- First the Stepper Motor moves the piston to a standard position (500). Then it measures the resonant frequency at that position, displays the resonant frequency for that position, “Done”, and the cavity length for that position in the List Box.
- The Stepper Motor moves the piston to a second standard position (1000) and follows the same procedure. After it completes the standard measurements for 500 and 1000, the phrase “Calibration Complete” is displayed in the List Box.
- The Stepper Motor zeros in on each target frequency by moving through the same steps, starting with the lowest frequency. It may take multiple iterations to get to the desired resonant frequency.
- When the position for the last frequency has been determined, you will see “Done” displayed in the List Box and in the lower left corner of the screen (Location B in figure 3)

 **TIP** – The visual graphic depicting piston positions (location C in figure 3) is not updated to reflect new settings until after the “Find Positions” step has been completed at the updated settings.

**Step 3. Auto Calibrate.** Stepper produces a stimulus and measures the SPL at each position, then calculates Thévenin equivalents and displays Quality metrics for each sound source.

- The text in the List Box will Display the word “Initializing”, then move to each position determined in Step 2 from cavity 0 (lowest frequency) to the highest cavity number.
- The List Box will display “Saving Calibration” after the last frequency has been measured.
- The resonant frequency for each sound source and each cavity will be displayed in the List Box
- A set of six PRB quality metrics will be displayed for each sound source (see table 1)
- The pressure measurements for the calibration will be automatically saved in a .PRB file and the name displayed in the List Box.
- The Quality metrics will be saved in a txt file with the same name as PRB file.
- A THS file with Thévenin characteristics will also be saved if you specified that in the Settings step.

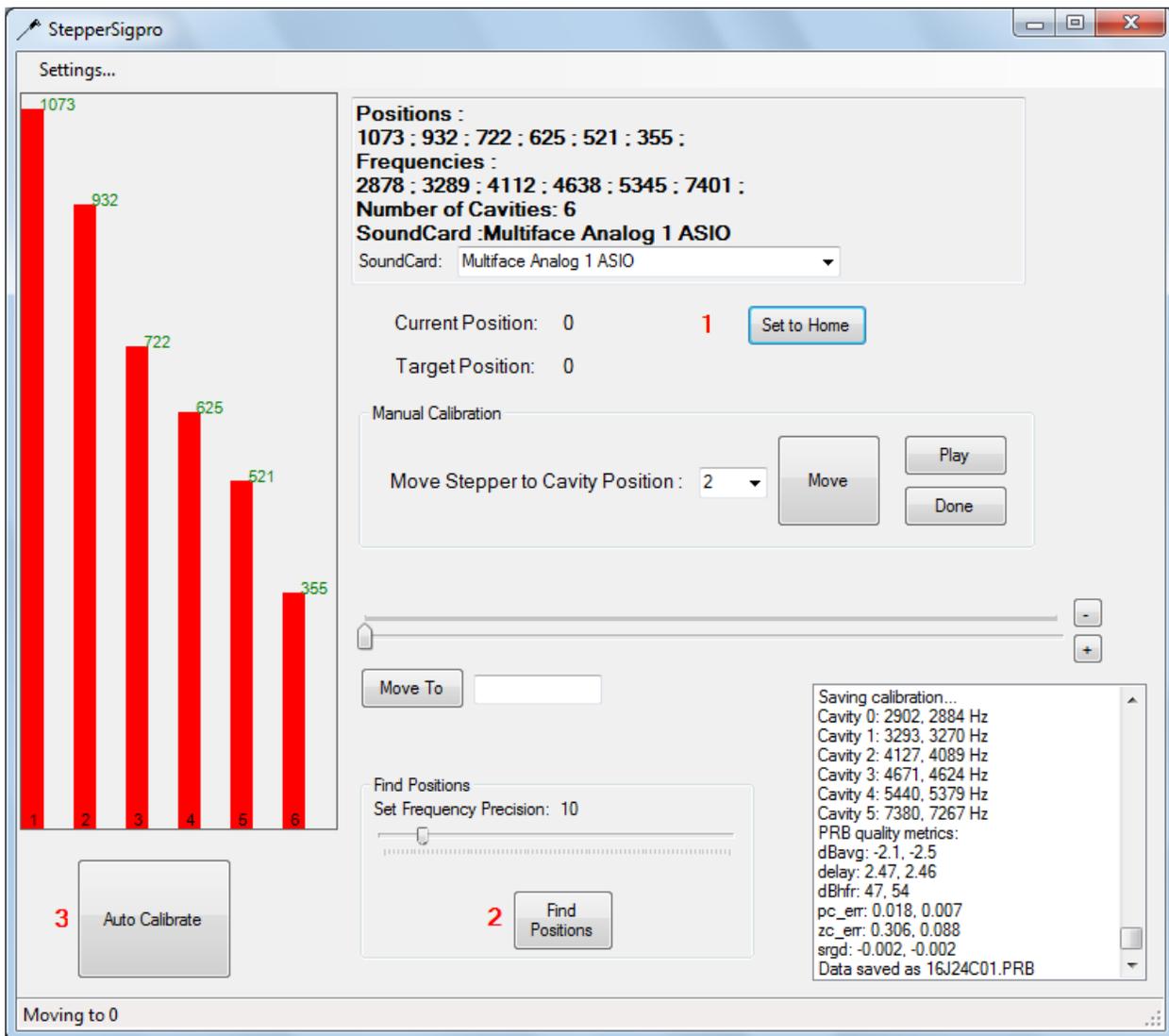


Figure 4. Example of completed automated calibration.

### Thévenin calibration Using Physical Cavities (Figure 5):

**Step 1.** Deselect “Use Stepper Motor” in the Stepper Motor settings tab of “Edit Settings” (figure 6). You do not need to enter any values. Notice that the main screen will look just as it did when Stepper Motor was selected, as shown in Fig. 6. The previous frequencies and number of cavities remain on the screen but none of these values apply any longer.



Figure 5. Physical Cavities.

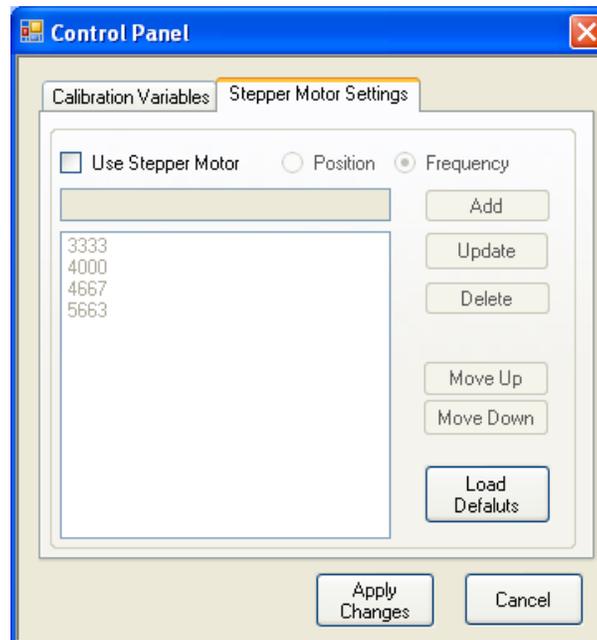


Figure 6. Example of menu when you de-select “Use Stepper Motor” to perform calibration with physical cavities.

**Step 2.** Move the probe assembly from cavity to cavity in descending length, playing the stimulus and measuring the SPL output in each cavity.

- In the Manual Calibration section of the main screen, position the probe assembly in the longest cavity (cavity 0) and click “Play”. In the List Box you will see, in sequence: “Initializing”, “Cavity 0”, and “Cavity 0 Done”.
- Change the probe assembly to remaining cavities (labeled 1, 2, 3,) and click “Play” after each cavity. After the last cavity, you will see “Cavity Done,” in the List Box.
- Click the “Done” button to save the calibration (Figure 7). The program calculates Thévenin characteristics, displays quality metrics, and writes a PRB and THS file.

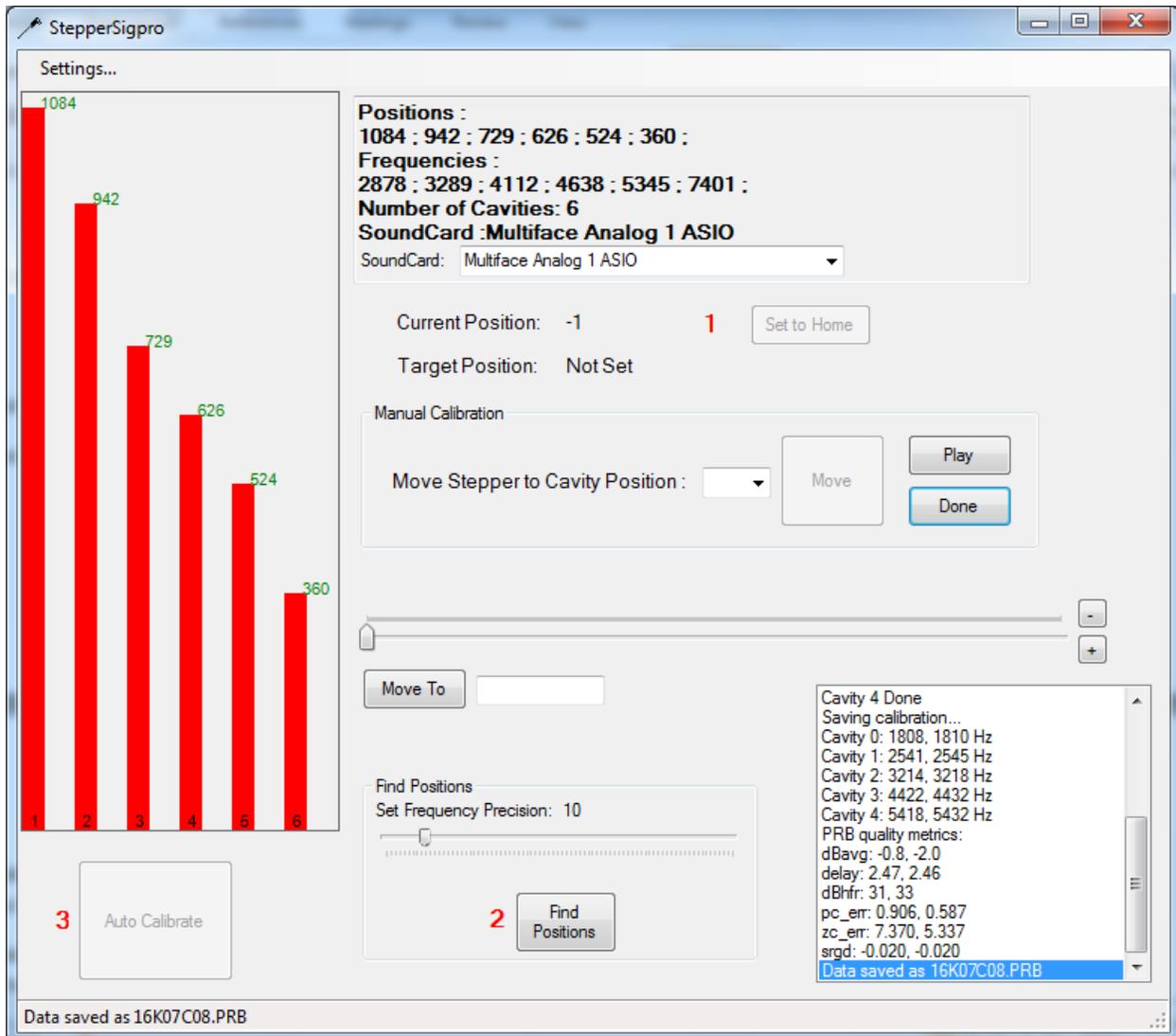


Figure 7. Example of a completed calibration using physical cavities.

### **Output Files:**

Six different output files may be created using either the Manual or the Automatic Method:

Lc00 and Lc01 – text files with cavity lengths calculated from the resonant frequency (overwritten each time).

THS file – A MATLAB binary file that contains Thévenin-equivalent source characteristics derived from a PRB file. (See the Appendix F of the [EMAV User Manual](#) for additional details).

PRB file – A MATLAB binary file that contains the responses for more than one acoustic cavity for each of the sound sources. A THS file can be created from a PRB file. (See the Appendix F of the [EMAV User Manual](#) for additional details).

Prbqm 01 and Prbqm00 – text files with quality metrics for each sound source (overwritten each time). Descriptions of these quality metrics are provided in Table 1.

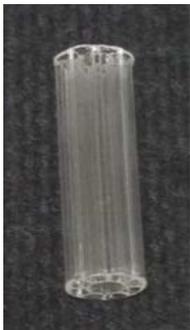
**Table 1. PRB Quality metrics**

Metric Name	Description	Acceptable Range
dBavg	Average pressure across frequency and across cavities.	0 to -2 dB/V
delay	Time difference between input and output.	2-3 ms
pc_error	Deviation between measured and ideal cavity pressure (2-8 kHz).	<0.1
dB hfr	Peak to dip ratio around 15 kHz	45-70 dB
zc-error	Deviation between measured and ideal cavity impedance (8-19 kHz).	<1.5
srgd	Measures source-reflectance group-delay. Quantifies the evanescent wave. Beveled front end tube (9 lumen tube) required to achieve this range (Etymotic ER10X-see Appendix A).	-0.005 to .001

**Appendix A: Beveled front end tube (9-lumen tube):**

Etymotic provides a front end lumen tube to be used with the ER10X. This standard tube results in generation of an evanescent wave that can affect sound pressure levels at higher frequencies and will result in source-reflectance group-delay (srgd) measurements outside the recommended range. The tube can be beveled by hand so that the medial portion of the outer 8 lumens have been cut at an angle, while the central lumen is unaltered. This results in a reduction of the evanescent wave and less impact on the sound pressure levels at higher frequencies. The srgd measurement with a beveled front end tube should be in the recommended range.

**Unbeveled Tube**



**Beveled Tube**

