Thermoacoustic Refrigeration Demonstration

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Abstract: A portable device for demonstrating thermoacoustic cooling is developed using off-the-shelf components and using atmospheric air as the working fluid. Use of off-the-shelf components leads to design considerations not encountered in high-performance devices. For example, the high mechanical resistance of the driver, which was intended for audio reproduction, dictates against making the driver co-resonant with the resonator, as is common when the driver is designed for operation at a specific frequency. Design is assisted by use of DELTAE software.

DESCRIPTION OF THE DEVICE

A portable device for demonstrating thermoacoustic cooling is developed using off-the-shelf components: the Morel MW-142 5" woofer and the Selenium HL 14–25 horn. The driver was chosen for its large diameter (3") voice coil and high Bl factor (7.5 N/A). The stack is a conventional rolled stack (1) made of Kapton® plastic. The Kapton is 5 cm wide, 76 μm (3 mil) thick, and 4.4 m long when unrolled. Strips of fishing line glued on at 6.4 mm intervals maintain a spacing of 280 μm (11 mil) in the rolled stack. The device uses air at atmospheric pressure for a working fluid, a choice that is simple but severely limits performance. The present incarnation of the device operates at a peak level of 3.5% of ambient pressure at 430 Hz, drawing 3 A rms, producing an unloaded stack temperature difference of up to 35 K. A schematic view is shown in figure 1.

![Figure 1. Cross-sectional side view of the demonstration device](image-url)

DESIGN CONSIDERATIONS

Use of off-the-shelf components leads to design considerations not encountered in high-performance devices. In retrospect, these considerations can be "predicted" using DELTAE (2). For example, thermoacoustic devices typically operate over a small frequency range, and drivers for refrigerators are designed with high Q and well matched to the (large) acoustic load. The driver is then also made to be co-resonant with the gas acoustics. In contrast, our driver was intended for audio reproduction, with high mechanical resistance (R_mechanical = 1.91 Ns/m, m_cone = 11.8 g) and poorly matched to our load. In this case, performance is actually degraded when the enclosure box is chosen to make the driver more nearly co-resonant with the gas. As another example, although the stock horn is not at all cylindrical, as a resonator it nonetheless gives a spectrum surprisingly and unfortunately harmonic in nature, initially causing the driver to distort well below its power limit. A DELTAE model is used to select a length of horn which puts the first four overtones far from harmonics of the fundamental, and the horn is cut to length as indicated. The choice of a relatively large diameter driver (for increased volume velocity) with a small stack (for...
increased pressure amplitude) requires the stack to be placed opposite the driver, in the "anti-Stirling" position, where traveling-wave thermoacoustic pumping opposes the standing-wave pumping (3). Stirling pumping is not considered in most manual calculations (4), so DELTAE is required to help select an optimum stack spacing to minimize anti-Stirling effects, as shown in figure 2. This analysis suggests that improvements can be obtained with a larger spacing than the "rule of thumb" spacing of a little more than two thermal penetration depths ($\delta_e = 130$ $\mu$m in air at 430 Hz).

![stack spacing and delta T](image)

**Figure 2.** DELTAE calculation of optimal stack spacing

**HEAT EXCHANGERS**

The hot heat exchanger has proven to be the most difficult problem encountered in terms of both design and fabrication. Since the cold "heat exchanger" is itself the heat load, it does not actually have to move any heat, and a piece of copper screen performs well. The hot heat exchanger, in contrast, must pick up heat from the air and then transport it away. For a small demonstration, where we wish to avoid the fans or pumps needed for fluid-backed exchangers (5,6), elements large enough to conduct sufficient quantities of heat tend to seriously degrade stack performance.

This project is ongoing. Improvements and other developments will be reported at the meeting.

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**REFERENCES**