Piezoelectric Fans

And Their Application In Electronics Cooling

Piezoelectric fans seem to represent an example of research and development that has culminated in a product that is deceptively simple. Although piezoelectric technology is capable of producing rotary motion, the fans operate quite differently from rotary fans, as they generate air flow with vibrating cantilevers instead of spinning blades. Piezoelectric, as derived from Greek root words, means pressure and electricity. There are certain substances, both naturally occurring and man-made, which will produce an electric charge from a change in dimension and vice-versa. Such a device is known as a piezoelectric transducer (PZT), which is the prime mover of a piezoelectric fan. See Figure 1. When electric power, such as AC voltage at 60Hz is applied, it causes the PZT to flex back and forth, also at 60Hz. The magnitude of this motion is very tiny, so to amplify it, a flexible shim or cantilever, such as a sheet of Mylar, is attached and tuned to resonate at the electrical input frequency.

Since piezoelectric fans must vibrate, they must use a pulsating or alternating current (AC) power source. Standard 120volt, 60Hz electricity, just as it is delivered from the power company, is ideal for this application, since it requires no conversion. If direct current (DC), such as in battery operated devices, is the power source, then an inverter circuit must be employed to produce an AC output. An inverter may be embodied in a small circuit board and is commercially available with frequency ranges from 50 to 450Hz. Driving the fan at resonance minimizes the power consumption of the fan while providing maximum tip deflection [1]. The cantilever is tuned to resonate at a particular frequency by adjusting its length or thickness [1]. The PZT itself also has a resonant frequency, so the simplistic concept of adjusting only the cantilever dimensions to suit any frequency may still not yield optimum performance. Conceivably, tuning the electrical input frequency to match existing cantilever dimensions may work, though with the same caveat - that the resonant frequencies of all the components must match, within reason. It is understood that no two fans have exactly identical resonant frequencies, due to unavoidable variations during manufacturing and assembly processes. Therefore, discrepancies are seen when comparing phase differences of actual fan motion and the driving signal. Although in-phase (or out-of-phase) excitation does not guarantee in-phase (or out-of-phase) vibration, the inherent phase difference is commonly measured at less than 5° for heat transfer experiments and the magnitude of its impact on the results is considered minimal [2]. Figure 2 shows how voltage and frequency affect the vibration amplitude.

Applications for piezoelectric fans are just in their infancy and could really thrive through the imagination of designers. See the rake-like fan shown in Figure 3. Integrating the cantilevers inside the fin channels of the heatsink is certainly an imaginative way to create a compact cooling package. Another significant realization in the interest of miniaturization is that the cantilevers don’t necessarily need to be in-line with the PZT. Imagine if the PZT was parallel with the base of the heart sink, and the cantilevers were angled into the heatsink channels. This would allow an ordinary heatsink to be packaged with a fan in an envelope barely larger than the size of the heatsink. Another approach to this compact concept is shown in Figure 4. Piezoelectric fans might never be a substitute for moving volumes of air that rotary fans already do so well, but they are ideal for cooling localized hot spots, dead air zones, and where space, power or noise considerations preclude the use of a rotary fan.

Another phenomenon that substantially boosts performance, but adds complexity to understanding the seemingly simple piezoelectric fan, is fluidic coupling. When two fans are operating simultaneously, a coupling phenomenon is observed which can cause an increase in vibration amplitude of as much as 40%, compared to an isolated single fan [2].
Heat transfer characteristics were determined experimentally for a pair of piezoelectric fans in two distinct orientations – vertically, as shown in Figure 5 and horizontally, as shown in Figure 6. Also known as orientation A and orientation B, respectively. The effect of fan coupling for each orientation is different for particular types of vibration. In orientation A, the vibration amplitude increased dramatically for in-phase vibration, while a decrease in amplitude was observed for out-of-phase vibration [2]. It is worthwhile to note that for this orientation, the limit of the minimum fan pitch depends on the phase difference between the two fans. Figure 7 shows where out-of-phase envelopes of vibration cannot overlap or else the fan tips will collide. For in-phase vibration, this is clearly not the case and the fan pitch can approach zero. To take advantage of this fact, and fit two fans in as small a space as possible, only in-phase vibration was considered during the experiments with orientation A [2]. The opposite effect of fan coupling was observed for orientation B, where out-of-phase vibration produced the greatest amplitude. Therefore, for orientation B, only out-of-phase excitation was considered. Experimental results for heat transfer coefficients with both orientations are summarized in Table 1, where the best case among multiple-fan experiments is compared to natural convection and single-fan performance experiments [2]. Results from both multiple-fan configurations are comparable and represent a 19-21% increase over a single fan and over a 650% increase compared to natural convection [2].

To isolate possible sources of coupling, another experiment was conducted to operate the fans in a vacuum chamber [2]. The single fan was observed to vibrate at much larger amplitudes than it did in air [2]. In fact, the vibration amplitude is comparable in a vacuum regardless of whether the single-fan or two-fan orientation was operated [2]. In contrast, the vibration amplitude for two fans under atmospheric conditions is larger compared to that of the single fan, making a clear conclusion that the most significant source of fan coupling is indeed fluid structure interaction [2]. Therefore, a part of the performance increase over a single fan is simply attributed to larger vibration amplitudes, while the remainder is due to the presence of the additional fan [2].

In order to integrate piezoelectric fans into practical cooling applications, they must be better characterized, and their performance metrics established [1]. Since they operate in a manner significantly different from traditional rotational fans, experiments have been performed to determine whether it is possible to develop fan curves that could be used as a basis for comparison against rotational fans [1]. Concluding that piezoelectric fans primarily mix the air near a heat dissipating device, it is reasonable to characterize them based on their efficiency in converting electrical energy into mechanical energy and transferring heat, rather than comparing them on the basis of steady flows generated by rotational fans [1].
Figure 3. Raked Fan Integrated with a Heat Sink [3].

Figure 4. Heatsink with Integrated Piezoelectric Fan [4].

Figure 5. Orientation A – Vertical, In Phase [2].

Figure 6. Orientation B – Horizontal [2].

Figure 7. Fan Pitch Limitation Due to Phase Orientation. Solid Lines Represent Instantaneous Fan Position While Dashed Lines Represent the Envelope of Maximum Vibration Amplitude [2].

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Best case convection coefficient [W/m²K]</th>
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<tbody>
<tr>
<td>Natural Convection</td>
<td>16.18</td>
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<tr>
<td>Single Fan</td>
<td>88.03</td>
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<tr>
<td>Orientation A</td>
<td>106.51</td>
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<tr>
<td>Orientation B</td>
<td>104.46</td>
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</tbody>
</table>

Table 1. Summary of Heat Transfer Experiment Results. Based on Average Surface Temperature and Input Heater Power of 1.6 Watts. [2].
References:
2. Kimber, M., Garimella, S., Raman, A., “An Experimental Study of Fluidic Coupling Between Multiple Piezoelectric Fans”, Cooling Technologies Research Center School of Mechanical Engineering Purdue University, 585 Purdue Mall, West Lafayette, IN 47907-2088

Advanced Thermal Solutions, Inc.
89-27 Access Road Norwood, MA USA
T: 781.769.2800 F: 781.769.9979
www.qats.com