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Geometric Optimisation of Piezoelectric Fan Arrays for Low Energy Cooling

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Abstract : Numerical methods are used to evaluate the operation of confined face-to-face piezoelectric fan arrays as pitch, P, between the blades is varied. Both in-phase and counter-phase oscillation are considered. A piezoelectric fan consists of a fan blade, which is clamped at one end, and an extremely low powered actuator. This drives the blade tip's oscillation at its first natural frequency. Sufficient blade tip speed, created by the high oscillation frequency and amplitude, is required to induce vortices and downstream volume flow in the surrounding air. A single piezoelectric fan may provide the ideal solution for low powered hot spot cooling in an electronic device, but is unable to induce sufficient downstream airflow to replace a conventional air mover, such as a convection fan, in power electronics. Piezoelectric fan arrays, which are assemblies including multiple fan blades usually in face-to-face orientation, must be developed to widen the field of feasible applications for the technology. The potential energy saving is significant, with a 50% power demand reduction compared to convection fans even in an unoptimised state. A numerical model of a typical piezoelectric fan blade is derived and validated against experimental data. Numerical error is found to be 5.4% and 9.8% using two data comparison methods. The model is used to explore the variation of pitch as a function of amplitude, A, for a confined two-blade piezoelectric fan array in face-to-face orientation, with the blades oscillating both in-phase and counter-phase. It has been reported that in-phase oscillation is optimal for generating maximum downstream velocity and flow rate in unconfined conditions, due at least in part to the beneficial coupling between the adjacent blades that leads to an increased oscillation amplitude. The present model demonstrates that confinement has a significant detrimental effect on in-phase oscillation. Even at low pitch, counter-phase oscillation produces enhanced downstream air velocities and flow rates. Downstream air velocity from counter-phase oscillation can be maximally enhanced, relative to that generated from a single blade, by 17.7% at P = 8A. Flow rate enhancement at the same pitch is found to be 18.6%. By comparison, in-phase oscillation at the same pitch outputs 23.9% and 24.8% reductions in peak downstream air velocity and flow rate, relative to that generated from a single blade. This optimal pitch, equivalent to those reported in the literature, suggests that counter-phase oscillation is less affected by confinement. The optimal pitch for generating bulk airflow from counter-phase oscillation is large, P > 16A, due to the small but significant downstream velocity across the span between adjacent blades. However, by considering design in a confined space, counterphase pitch should be minimised to maximise the bulk airflow generated from a certain cross-sectional area within a channel flow application. Quantitative values are found to deviate to a small degree as other geometric and operational parameters are varied, but the established relationships are maintained.

Keywords : piezoelectric fans, low energy cooling, power electronics, computational fluid dynamics
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