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Research Paper

Investigation of tuning-fork double piezoelectric fans with elastic base

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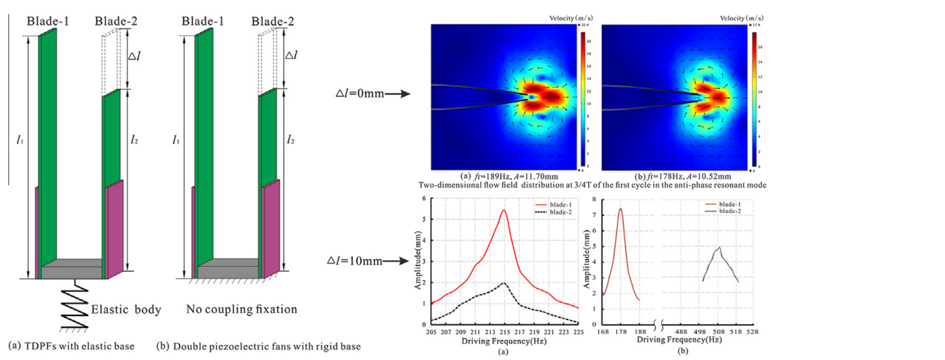
HIGHLIGHTS

- Tuning-fork double piezoelectric fans (TDPFs) with elastic base was investigated.
- The TDPFs can be excited to resonate by only single power.
- The TDPFs exhibits a larger thermal-dissipation capability compared with rigid base.
- The TDPFs provides a higher energy-keeping capability under some length deviations.
- The α of the TDPFs with elastic base is 25 times than that with rigid base.

GRAPHICAL ABSTRACT



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ABSTRACT

Existing double piezoelectric fans are usually driven by independent powers, and this is not economical. This study proposes tuning-fork double piezoelectric fans (TDPFs) with elastic base, which works in the anti-phase resonant mode. Two blades of the TDPFs can be excited to resonate simultaneously even with an asymmetric structure when driven by only single power. A prototype of TDPFs with elastic base is fabricated, analyzed, and tested. Results reveal that the TDPFs with elastic base exhibits a larger thermal dissipation capability than double piezoelectric fans with rigid base do when the two blades are identical at the same driving voltage. This finding is further verified through two-dimensional flow simulations in COMSOL. With the coupling of the elastic base, the TDPFs provides a higher energy-keeping capability when length deviations exist between the two blades. Results show that when driven by single power, the tolerance in length deviation of the TDPFs with elastic base could be 25 times larger than that of the double piezoelectric fans with no-coupling rigid base, with the same 20% decrease in thermal dissipation capability. Therefore, the proposed TDPFs with elastic base reduces the influence of fabrication errors or fixation discordance, and is more robust for practical applications.

1. Introduction

Advanced microelectronics bring enormous component density and heat flux generation, thus thermal management of modern consumer electronics gets extensive concerns [1]. Piezoelectric fans, as thermal dissipation equipment, have been widely investigated due to their extraordinary advantages including low mechanical noise, long life span, and low power consumption compared with traditional electromagnetic rotatory fans [2]. The performance of thermal dissipation [3–13] and the fluid field [14–17] of the single piezoelectric fan have also been extensively explored.

Fairuz et al. [3] verified that high modes of vibrations are ineffective and suggested that the fundamental resonance mode is suitable for practical piezoelectric fan applications. Air flow

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Nomenclature

A_0	amplitude of the two blades (mm)
A_1	amplitude of blade-1 (mm)
A_2	amplitude of blade-2 (mm)
A	equivalent amplitude (mm) $\left(\sqrt{A_1^2 + A_2^2}\right)$
E	Young modulus (Pa)
$Y_1(x)$	the first-order vibration mode function of the cantilever beam
t	time (s)
f_r	resonance frequency (Hz)
$f_r \times A$	thermal dissipation capability of the system with different length deviations between the two blades (Hz mm)
$f'_r \times A'$	thermal dissipation capability of the system with no length deviation (Hz mm)
k	equivalent stiffness of the spring
k_1	equivalent stiffness of blade-1
k_2	equivalent stiffness of blade-2
k_c	coupling elastic coefficient between blade-1 and blade-2
l_1	length of blade-1 (mm)
l_2	length of blade-2 (mm)
l	length of the blade
Δl	length deviation between blade-1 and blade-2 (mm)
m	equivalent mass of the spring
m_1	equivalent mass of blade-1
m_2	equivalent mass of blade-2
h	thickness of the blade (mm)
x_1	displacement of m
x_2	displacement of m_1
x_3	displacement of m_2

Greek symbols

α	tolerance in length deviation between blade-1 and blade-2
ρ	density (kg/m^3)

generated by the fan primarily influences only a small area around the fan tip [8]. Therefore, a single piezoelectric fan fails to satisfy the cooling demand in some circumstances. To increase the sweep area and the thermal dissipation capability, some researchers focused on double [18–20] and multiple [21–25] piezoelectric fans.

Sufian et al. [18] investigated the influence of dual vibrating fans on flow and thermal fields through numerical analyses and experimental measurements. They found that the single fan enhances heat transfer performance within approximately 2.3 times for the heated surface. By contrast, the dual fans enhance heat transfer performance within approximately 2.9 and 3.1 times for out-phase and in-phase vibration, respectively. For the practical application of double piezoelectric fans, Sufian et al. [19] further examined the heat dissipation efficiency of the high-power LED package operating under double vibrating fans. Their results indicate that the double piezoelectric fans enhance the heat transfer performance by approximately 1.3 times larger than the single fan does. Chung et al. [20] proposed coupled piezoelectric fans formed by clamping two fans in parallel and attaching a flexible wing and a soft polymer skin. The phase delay between the driving voltages supplied to the two coupled piezoelectric fans controls the flapping and twisting motions of the wing. Ma et al. [21,24,25] also found a new mechanism to set the connection between fans by combining piezoelectric, magnetic, and resonance effects to drive passive fans vibrating simultaneously. It can realize one piezoelectric plate to drive multiple fans.

Existing studies have demonstrated remarkable achievements on double piezoelectric fans, but most studies established on the simple permutation and combination of single piezoelectric fan [18,19]. The relationship between the piezoelectric fans is rarely involved. When fabrication errors or fixation discordance occur, similar first-order inherent frequencies of each piezoelectric fan are difficult to achieve. Therefore, existing double piezoelectric fans with no-coupling fixation are usually driven by independent powers as shown in Fig. 1. With the increasing number of piezoelectric fans, they cannot be easily economized and popularized in the thermal dissipation field. In general, piezoelectric fans are directly fixed on a rigid base, which consumes quite an amount of vibration energy. This is not allowed in some vibration-sensitive occasions. Thus this study proposes tuning-fork double piezoelectric fans (TDPFs) with elastic base, which works in the anti-phase resonant mode. It is economical because the two blades can be excited to resonate simultaneously even with an asymmetric structure when driven by only single power. As a comparison, the double piezoelectric fans with no-coupling rigid base is also analyzed. The thermal dissipation capability is measured by the experiment, and two-dimensional flow simulations in COMSOL are conducted to further verify the experimental results. Besides, the tolerances in length deviations existing between the two blades are investigated by experiments.

2. Structure and working principle

The prototype and dimensions (unit: mm) of the proposed TDPFs with elastic base are shown in Fig. 2. The TDPFs with elastic base are composed of the piezoelectric (PZT) plates (PZT-4, Hunan Jiayeda Electronics Co., Ltd.), an aluminum blade, a polymethyl methacrylate link block, and a spring. They are bonded with each other by the epoxy of DP460. The selection of link block and spring is not the focus of this study but should still be seriously considered, thus some brief descriptions about them are mentioned. For

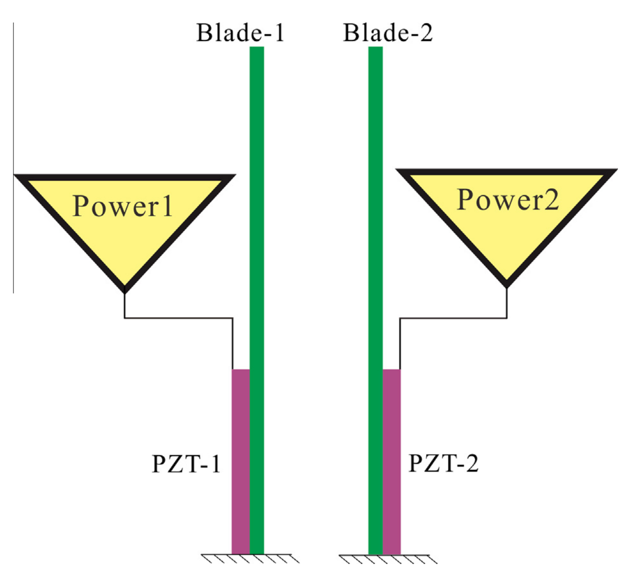

Fig. 1. Existing double piezoelectric fans with no-coupling fixation driven by independent powers.