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Piezoelectric Fans: A Narrative Review

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ABSTRACT

Piezoelectric Zirconate Titanate (PZT) is a material that has many applications. One of its application is in piezoelectric (PE) fans. PZT material that acts as an actuator, by sticking to the surface of a beam or plate-like structural element, or by embedding in it a sandwich blade is obtained. The blade in the shape of a beam or plate is exposed to vibration by applying AC voltage to the PZT actuator. The blade that is exposed to vibration ensures the removal of hot ambient air. In recent years, PE fans have been used in technologically sensitive areas for heat transfer due to some important advantages. Therefore, literature survey shows that there are many studies about fans with PE actuators. In this review paper the historical background and the research areas of studies on PE fans are explained in detail to readers. Studies on the electro-mechanical properties and components of PE fans are described in detail. In addition, innovative analytical, numerical and experimental studies on PE fans in the open literature were investigated. Finally, the visual representations of the physical and experimental models used in the studies are summarized in a table. According to literature survey, it is clear that studies on PE fans have only recently begun and are gradually advancing. In particular, analytical modeling and fan blade solving methods, vibration control, blade-actuator optimization for optimum energy performance with minimum energy, experimental setups to accurately measure blade velocity and performance, the types of used PZT materials are the most popular research topics.

Keywords: Piezoelectric fans, vibrating cantilevers, heat transfer enhancement

1 Introduction

The piezoelectric effect is a linear-electromechanical reaction between electrical and mechanical conditions in insulating materials and crystals that do not have a central symmetry [1-2]. Piezoelectricity is the conversion of mechanical energy into electrical energy or electrical energy into mechanical energy [3]. In recent years, the reverse piezoelectric effect has attracted the attention of researchers with the development of microelectromechanical systems [4]. One of the important elements based on piezoelectric crystal is fans [5]. PE fans were preferred as a low-consumption tool in various industries to increase convective heat transfer [6]. PE fan with ease of operation, compact size, low noise emission, and low energy consumption, has recently become one of the preferred methods to increase heat transfer performance [7]. Fans based on PZT material are supported by various flexible blades. Applying an electric field to PZT crystal surfaces causes deformation and irregularity on its surface [8]. The piezoelectric actuator is placed on the blade with its sides clamped. Thus, horizontal expansion is converted to vertical displacement by clamping the sides of the piezoelectric actuator [9]. An alternative input signal in the piezoelectric element causes vibrations along the beam and can be used to induce

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fluid flow around this element and improve heat transfer. It is worth mentioning that the vibration performances of piezoelectric actuators are directly correlated with the applied amplitude and frequency. In addition, the miniaturization of PE fans has attracted the attention of researchers in recent years [10]. In this study, innovative studies on PE fans were presented. The purpose of this study was to enable researchers interested in PE fans to investigate this issue transparently. The paper is organized as follows. The factors affecting the working principles of PE fans and the innovations presented in the open literature are provided in Sections 2 and 3. Finally, the concluding remarks are reviewed in Section 4.

2 PE Fan Parameters and Characteristics

This section has been prepared to better understand the work done so far and to follow the PE fan development processes more easily. Therefore, the components and characteristic parameters of the PE fan are fully described in this section. In addition, different methods used in fan design and their advantages and disadvantages were explained based on the information available in the open literature.

2.1 The Effects of Mechanical Factors on The PE Fans Performance

In this section, the mechanical factors examined in the open literature are discussed. Thus, innovative studies in the open literature were covered in detail (see Figure 1) and the interactions of each component in the performance of PE fans are examined. For example, Liu et al. (2009) investigated parameters such as the distance of the PE fan to the heat source and the vertical or horizontal fan arrangement. It has been determined that the heat transfer performance in the horizontal fan arrangement is not less than the vertical arrangement [11]. Abdullah et al. (2009) investigated the effect of PE fan position on the heat transfer coefficient. This study was investigated by analytical and experimental methods. Consequently, it was observed that the height of the PE fan can reduce the surface temperature of the heat source to 68.9 °C [12]. Abdullah et al. (2012) investigated the effects of gap type and PE fan vibration amplitude on heat transfer. In this study, the effect of the piezoelectric actuator on the temperature distribution in two- and four-blade heatsink configurations was investigated. Finally, it has been presented that the four-bladed piezoelectric based cooler exhibits high performance [13]. Lin (2012) studied the fluid behaviour in the PE fan using analytical and experimental methods. Moreover, heat transfer was investigated in horizontal and vertical coordinates. It was concluded that the heat transfer coefficient improves 1.6-3.4 times when the heat source is in the vertical position and 1.8-3.6 times when it is in the horizontal position [14]. Huang et al. (2012) developed a three-dimensional computational model to increase the performance of PE fans. Thus, Levenberg–Marquardt Method (LMM) and CFD-ACE+ codes were used to calculate the minimum level of temperature. In addition, displacement was measured experimentally with an infrared thermal scanner. Consequently, it was noted that the optimal position of the proposed PE fan occurs at a position approximately 3.5 mm below the centre point of the fin plate [15]. Ma et al. (2013) developed a multi-fan cooling system working with PZT and magnetic forces. In addition, the distance between the fans and the heatsink and the effects of power consumption were investigated. Consequently, the temperature was reduced to 17 °C at 0.03 W power consumption under desired conditions [16]. Shyu and Syu (2014) designed a four-bladed PE fan and studied heat transfer by experimental and analytical methods. As a result, during the heat transfer enhancement between the two blade arrays of the aluminium based fan, the fans drove the airflow with a moderate Reynolds number [17]. Lin et al. (2016) proposed a five-blade PE fan based on PVC or PET. As a result, it was found that a wider blade had a greater velocity, so a narrowed blade was better for heat sources than a different rectangular shape [18]. Hales and Jiang (2018) designed a piezoelectric based multiple fan array for alternative thermal management systems. In this study, the effects of electrical factors on the performance of the PE fan were investigated. Eventually, it has been obtained that there is a linear correlation between frequency, amplitude and air flow rate [19].

Huang et al. (2021) investigated the heat transfer rate numerically and experimentally with the synthetic jet impingement method on a single fin configuration. Consequently, a linear correlation between fin array and cooling performance was obtained. Finally, horizontal fan arrangement has been found to provide better cooling [20].

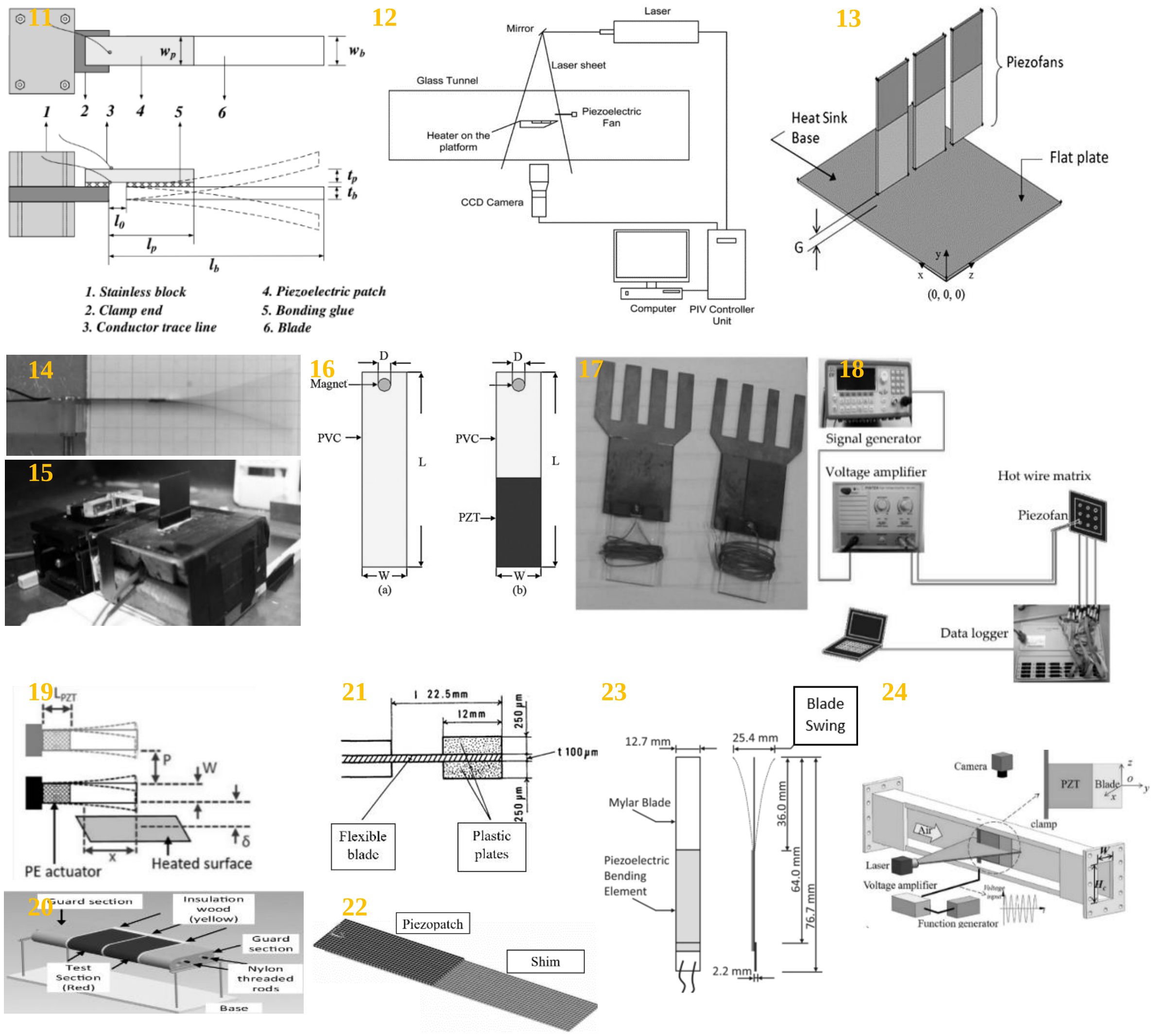

Figure 1: Structure configuration examples of PE fans

2.2 The Effects of Electrical Factors on The PE Fans Performance

In this section, the effects of electrical parameters on the performance of PE fans were investigated. There are many studies examining electrical parameters in the open literature (see Figure 1). For example, Yorinaga et al. (1985) studied the performance of the PE fan at different amplitudes. In this study, the air movement around the blade profile was investigated by the Schlieren method. The sound level of the PE fan was compared with that of the motor fan, which had the same airflow performance, Thus, it was concluded that the PE fan operates 3 dB (A) quieter than the conventional motor fan [21]. Wait et al. (2007) analysed the performance of PE fans operating in high resonance modes analytically and experimentally. An impedance analyser was used in the experimental measurements to determine the resonant frequencies. The effect of the resonance mode on the flow profile was presented with the visualization technique. Consequently, it is stated that the number of modes has linear and non-linear correlations with power consumption and flow rate, respectively [22]. Ma et al. (2015) preferred a system with two PE fans to make the heat transfer process expeditious. Thus, continuous and high heat flux at lower amplitudes was obtained [23]. Chen et al. (2020) analysed the heat transfer performance of the proposed PE fan analytically. In this study, the working principle and performance of PE fan with Structure Boundary Detection Algorithm and Fast Fourier Transform Algorithm were investigated. In addition, the heat transfer performance of the PE fan with temperature-sensitive paint was experimentally measured. Consequently, there was a 46% improvement in the performance of the proposed novel PE fan at 43 Hz [24].

3 Taxonomy of Previous Studies

There are many studies on this subject in the literature. In this section, the working principles and investigation methods of PE fans are examined in detail.

3.1 Analytical Modelling of PE Fans

This section contains innovative studies that analytically analyse the performance of PE fans. The purpose of this section is to examine the mathematical expressions used in analytical studies. There are many studies available in the open literature (see Figure 2). For example, Yao and Uchino (2001) studied the damping effect on mechanical wobbling. In addition, the effects on vibration were investigated by adding mass to the end of the plate. Consequently, magnitude deflections were obtained at low frequencies [25]. Lin (2013) used the visualization technique to study the behaviour of the fluid flow around the fan tip and cylindrical surface. In addition, three-dimensional simulations are carried out to investigate the detailed properties of the heat and fluid flow fields produced by the PE fan. Finally, the experimental results confirm the results obtained by the numerical method [26]. Li et al. (2018) proposed a dual PE fan to increase convective heat transfer performance. In addition, the effects of electrical factors on heat transfer were covered. It was observed that single and dual fans produce very close heat transfer coefficients [27]. Hu et al. (2020) analytically analysed the effects of a PE fan array in a solar air heater. Two different downstream configurations were tested, including counter flow and downstream. The results showed that the PE fan as a vortex generator can effectively increase the local and average Nusselt number [28]. Qing et al. (2020) designed a new air cooling system for a control box. The Flotherm special thermal modelling method was used for the simulation of this system [29]. Ding et al. (2020) analysed the horizontal cooling performance of a heated wall from PE fans. In this study, dynamic mesh technology is used to make analytical simulations of the air flow and heat transfer properties of the PE fan [30].

3.2 Numerical Modelling of PE Fans

Numerical analysis deals with the formulation, study and application of approximate computational methods to solve these problems of continuous mathematics (as opposed to discrete mathematics) which cannot be solved by analytical and precise methods. Innovative numerical studies on PE fans are covered in this section to examine in more detail (see Figure 2). For example, Lin (2013) simulated the heat and flow behavior around a cylindrical structure in FLUENT 3D. In conclusion, this study examined the effects of the separation distance between the fan tip and the heated surface and the amplitude of the fan tip for the cylindrical heated surface [31]. Jiahong et al. (2021) investigated the eddy change and heat transfer of the PE vibrating cantilever in liquid-cooled channels. Consequently, it was obtained that the liquid density was inversely correlated with the vortex shedding strengt and the radius of the core [32].

3.3 Experimental Analysis of PE Fans

In the open literature, there are many studies that experimentally examine the working principles and performances of PE fans (see Figure 2). In this section, studies with striking innovations are included. For example, Schmidt (1994) experimentally investigated the performance of the proposed novel PE fan. experiments were carried out using naphthalene sublimation technique with certain boundary conditions. Finally, an equivalent jet Reynolds number is presented, which will provide the same surface-averaged Sherwood number as that obtained with the PE fan, in comparison of the present experimental results with the jet impingement flow [33]. Acikalin et al. (2004) proposed a PE fan for the cooling of portable electronic devices [34].

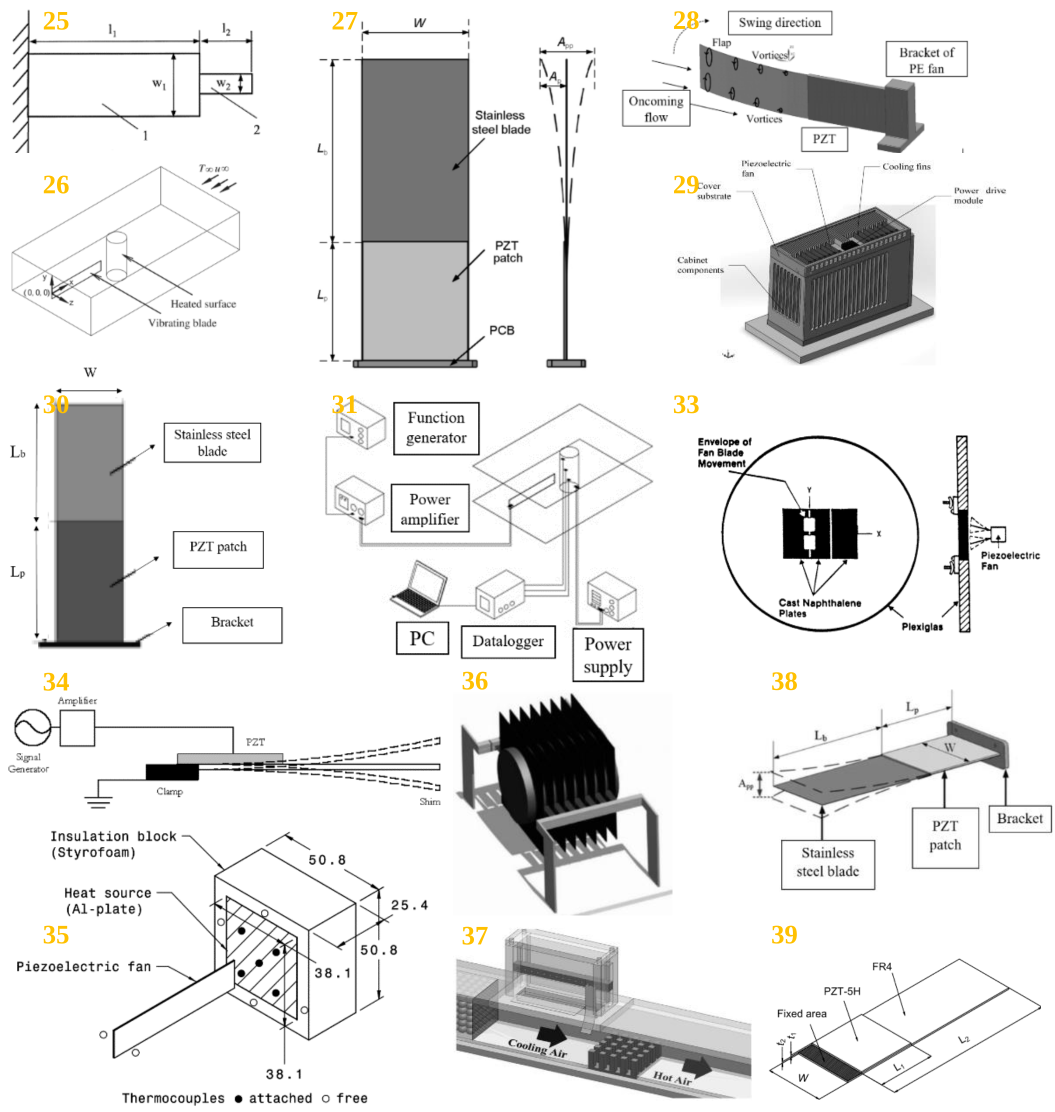

Figure 2: Studies on PE fan technology

Açıkalın et al. (2007) analysed the potential of using PE fans in the thermal management of electronic components analytically and experimentally. The Design of Experiments (DOE) approach was used for experimental design. As a result, a 375% increase in the convective heat transfer coefficient was achieved, resulting in a temperature drop of more than 36.4% at the heat source [35]. Gilson et al. (2012) prepared two different experimental setups for fluid flow characterization and the thermal enhancement capabilities. Consequently, it has been obtained that the Fin Side Walls (FSW) fan is not as efficient as the Fin Base (FB) in cooling [36]. Jeng and Liu (2015) experimentally investigated the effect of the air flow in the blade and the heat-collecting receiver on the heat transfer [37]. Li et al. (2017) studied the convective heat transfer output of cross-flow around the vibration envelope of a PE fan. As a result, it was observed that the combined performance of fan-induced heat transfers and fan vibration envelope improves the convective heat transfer that occurs near the fan vibration envelope [38]. Qiu et al. (2020) investigated the local heat transfer enhancement caused by a PE fan interacting with axial flow in the heated channel. The experimental result showed that the heat transfer performance of the heated surfaces is greatly enhanced by a vibrating PE fan. In the simulations, the spring-based smoothing method and the local remeshing technique were used to solve the moving boundary problems. Finally, the numerical result shows that the increase in heat transfer is obtained from the vortex pairs generated by the PE fan, which significantly enhances the heat exchange between the main flow and the near-wall flow [39].

4 Conclusions

In this study, researches on PE fans in the open literature were investigated in detail. Analytical, numerical, and experimental methods were used in the studies. Three-dimensional computational models have been developed. Almost all studies have shown that PE fans have high performance in the field of heat transfer. Low energy consumption, controllability, design and fabrication facility, compact and small size, safe and long life can be considered as the most important advantages of PE fans. Ultrasonic high-frequency noise is identified as its most important disadvantage. There is a wide selection of materials for PE fans and actuator blades. The width of the blade and PE actuator increases performance. In addition, increased blade stiffness reduces fan performance. In multi-blade PE fans, the number of blades has a significant effect on the Nusselt number. It has been determined that the Schlieren type PE fan operates 3 dB quieter than the conventional motor fan. It has been stated that the number of PE patches used in the fan blade reduces the power. It is found that the vibration mode with the best performance is the first vibration mode. Higher modes reduce performance and energy consumption.

5 Declarations

5.1 Study Limitations

None.

5.2 Acknowledgements

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5.3 Funding Source

None.

5.4 Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5.5 Authors’ Contributions

Hamid ASADI DERESHGI contributed with the paper writing and revisions.

Huseyin DAL contributed with the paper writing and revisions.

Rabia Güzide AL contributed with the paper writing and revisions.

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