Microelectronics Reliability 63 (2016) 342–353

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/mr

Review paper

Piezoelectric oscillating cantilever fan for thermal management of electronics and LEDs — A review

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ARTICLE INFO

Article history:
Received 4 April 2016
Received in revised form 7 June 2016
Accepted 10 June 2016
Available online 19 June 2016

Keywords:
Piezoelectric fan
Oscillating cantilever
Active cooling of electronics
Cooling of LEDs

ABSTRACT

This review discusses piezoelectric fans and their feasibility in a cooling of electronics components and LEDs. The discussion will be restricted to fans based on an oscillating cantilever, the construction which is best known. Other possible piezoelectric fan constructions will be just shortly mentioned. Since the invention of a piezoelectric fan in late 1970s, at least hundreds of science papers have been published about them. A general level presentation of the subject and a summary of the research outcomes will be presented. The construction and operation principles of a piezoelectric fan will be presented. An introduction to piezoelectric materials will be given. The most important equations covering the oscillation of a cantilever beam and the equations for designing fan's geometry will be presented. The generated air flows of a single piezoelectric fan will be issued. This subject will be approached by executing some computational fluid dynamics (CFD) simulations. Use of an air nozzle can force the air vortices closer to laminar flow and improve the cooling effect. The rather weak air flow of a single fan motivates to use multiple fans. A large number of studies have been published about multiple fan constructions. A piezoelectric fan will be compared with a conventional radial fan. An introduction to the electrical parts of a piezoelectric fan will be given. An experimental work demonstrating the use of a piezo fan for electronics cooling will be executed.

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http://dx.doi.org/10.1016/j.microrel.2016.06.008
0026-2714/

1. Introduction

A piezoelectric fan and its use for cooling electronics components have been known since the end of 1970s. Integration of electronics and increasing density of electronics packaging requires new solutions for cooling. Passive or active cooling is usually needed for processors, display drivers and many power electronics components. LED lighting is a new application area which grows fast. In order to maintain high light generation and long lifetime proper temperature management of individual LEDs or LED multichip modules must be arranged. Passive cooling is a common solution. This usually means using a heatsink. Heatpipe is a passive cooling method which nowadays is rather often used. If passive cooling is not efficient enough, active cooling methods must be used. Even nowadays, the most common active cooling arrangement is still the combination of a heatsink and a radial fan. The lifetime of a good quality radial fan is typically around 20,000 h. This is still much too short in comparison with the lifetime of high reliability electronics devices or typical LEDs. For many applications the power consumption of a fan is also much too high. In order to meet the requirements of a long lifetime, high cooling capability and efficiency, novel active cooling methods must be implemented. The piezoelectric fan, which features low power consumption, high reliability and long lifetime, low cost and low noise, can fit well in those requirements. All of these characteristics of a piezoelectric fan match well with present day LED technology. For these reasons piezoelectric fans are gaining more acceptance especially in LED lighting applications.

A piezoelectric fan (Fig. 1) which is based on a piezoelectric material patch and an oscillating cantilever attached to it. In literature different names are used for the cantilever. When speaking about fans, it is called either a blade, a shim or a beam. In this paper word beam will be used exclusively. The special characteristic of a piezoelectric material is that it is bending when an electric field is applied over it. The bending is caused by the expansion of the surface and contraction of the opposite surface. Although the used electric field is rather strong, bending is measured only in some micrometers. The bending itself cannot generate a significant air flow. A thin beam made of flexible material will be attached to the piezoelectric patch. This construction can be made oscillating if external energy is delivered into it. The structure will start to oscillate at its specific resonance frequency. There are numerous resonances, but the first fundamental resonance frequency is the best for fan operation. Beam oscillation with significant amplitude takes place just at the resonance. The oscillation attenuates quickly if the frequency of the external drive is even slightly shifted away. In the oscillation, electrical energy will be transformed to a mechanical energy which move the beam and at the resonance conditions this actualizes with the maximum efficiency. Typically a piezoelectric fan will be made to operate at low frequencies between 20 and 100 Hz or even below 20 Hz which is the practical limit of an audible sound. While operating, a piezoelectric fan is very silent or even non-audible. Sinusoidal waveform is the most often used for driving a fan as it results in the best efficiency.

A fan produces rotating air flows on both sides of the beam and the fan tip produces jet-like air stream which propagates ahead. All these air flows can be used for cooling. Considering the heat transfer capability all these flows provide the same magnitude of cooling enhancement [1]. Depending on the used air flow, there are two choices for the configuration. Either the beam locates above the plate to be cooled or the beam locates in front of the plate. In both cases, the beam can be either vertically or horizontally oriented. In case the beam locates above the plate, it can extend over the plate partly or entirely. Whatever arrangement is used, efficient cooling effect is possible only if the distance between the beam and the plate is no more than a few millimeters. Fig. 3 shows the typical fan orientations. In some cases cooling effect can be improved by a well-designed air nozzle. The most efficient solution might result when a fan is partly or totally integrated inside a heatsink (Fig. 2).

Nomenclature

A	oscillation amplitude [m]
A_n	amplitude of the nth natural frequency [m]
D	piezoelectric fan width [m]
E	Young's modulus [N m^{-2}]
F	force [N]
f_{osc}	resonance frequency of piezoelectric fan [Hz]
h	convective heat transfer coefficient [W m^{-2} K^{-1}]
I	moment of inertia [kg m^2]
K_{pf}	stiffness of cantilever beam
L	length of fan [m]
L_b	length of cantilever beam [m]
L_p	spacing between fans in multifan configuration [m]
L_{pzt}	length of piezo element [m]
m	mass of cantilever beam [kg]
m_{eff}	effective mass of cantilever beam [kg]
n	order of natural frequency of vibrating cantilever
$P_{elec.}$	electrical power, consumption [W]
$P_{stat.}$	static pressure [Pa]
Re	the Reynolds number
R_{th}	thermal resistance [K W^{-1}]
R_0	thermal resistance in natural convection conditions [K W^{-1}]
T_{hs}	heatsink temperature [K]
T_{amb}	ambient temperature [K]
Q	heat flow [W]
Greek letters	
δ	distance from fan tip to hot surface [m]
η	improved thermal performance of cooling system
ρ	density [kg m^{-3}]
υ	kinematic viscosity
ω	angular frequency of oscillation

2. Early history of a piezoelectric fan

The first study about piezoelectric fans for electronics cooling was published by Minoru Toda and Susumu Osaka in 1978. The followed

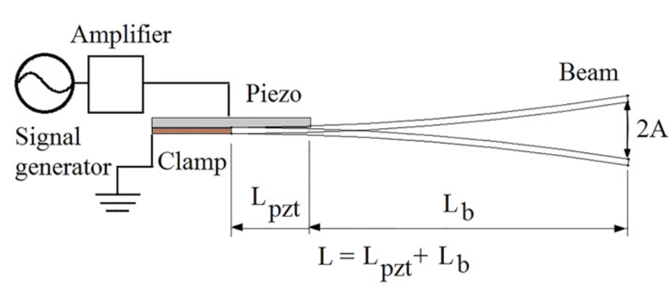

Fig. 1. Piezoelectric (unimorph) fan and its operation on the fundamental resonance frequency.