Piezo Fan for Thermal Management of Electronics

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In order to satisfy the demand for light-weight, low power consumption, and compact-sized personal computers, portable electronics, LED applied products and audio electronics, we have developed a 'piezo fan' that works on a different principle from that of motor fans. By using the finite-element method for design support, the demands for long life and compact size were achieved. Also, on the basis of the supposed application, the cooling effects and the cooling possibilities of piezo fans were confirmed by applying them to the heat sources of personal computers, portable electronics, and LED applications.

1. Introduction

Most people imagine a heat sink and a fan on a CPU when thermal management of electronics is mentioned. However, in this field, people are looking for improvements or replacements of current fans because there are still many issues such as fan noise, power consumption, size, and the life issue due to wear of the bearing.

One important issue of axial fans is that there is no air flow around the center of the rotation center of the fan, and the air flow is vortex flow. Since heat sinks usually have a linear flow channel, the air flow cannot cool the heat sink effectively.

Piezo fan has been researched and developed because it has features of low noise and low power consumption[1)]. Lately, more researches have been conducted because people think that piezo fan can fulfill the demands of electronics cooling module such as light weight, low noise and compact size[2) 3)]. In this research, we first realized the basic demand for the life and robust issue. Then, according to the features including air flow and shapes, we designed and tested compact cooling modules according to the demands of mobile electronics with multiple heat sources, low cost PC and LED modules.

2. Operation principle and characteristics of piezo fan

2.1. Operation principle of piezo fan

The electric field induced strain of piezoelectric element is called “inverse piezoelectric effect”. Normally, this strain itself is too small to use. In order to obtain more displacement, a metal or a plastic sheet (blade) is attached on the piezoelectric element, so that it can bend as a bimetallic strip. As shown in Fig. 1(a), this structure bends upward while applying a positive voltage and downward while applying a negative voltage. Although the displacement is enough in some fields, it is still not large enough to generate air flow for cooling. By elongating the blade and actuating the structure at its resonant frequency as shown in Fig. 1(b), the free end of the blade resonates with large displacement and thus the requisite air flow becomes available.

2.2. Characteristics of piezo fan

Figure 2 shows the relation between the actuation

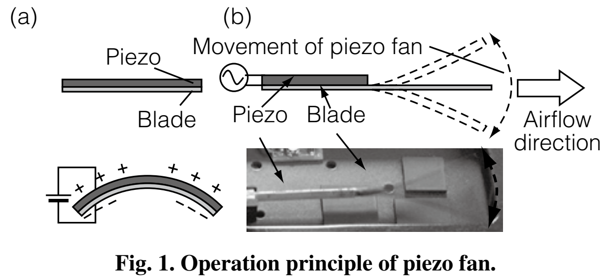

Fig. 1. Operation principle of piezo fan.

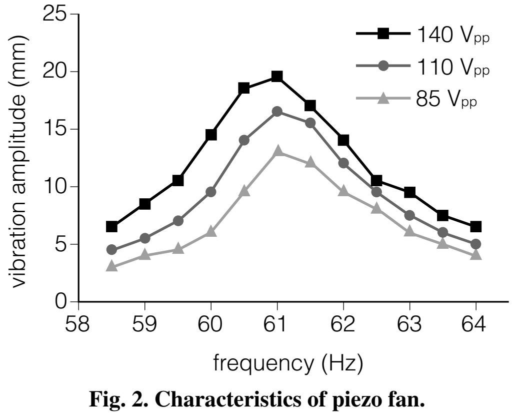

Fig. 2. Characteristics of piezo fan.

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Panel 1. Abbreviations, Acronyms, and Terms.

Piezo—The materials with the ability to generate electric field in response applied Strain
LED—Light-Emitting Diode
CPU—Central Processing Unit
PC—Personal Computer
FEM—Finite Element Method
dBA—A sound pressure unit simulating the human-ear response

frequency and the amplitude of the piezo fan tip while applying sine voltage to it. Strain of piezoelectric element is almost proportional to the applied electric field, thus increase in the voltage (Vpp) increases the strain energy and piezo fan amplitude. The result in Fig. 2 also indicates that the amplitude has a maximum value at some specific frequency. This is because piezo fans use resonance for larger amplitude and more air flow.

2.3. Low driving voltage piezo fan

Due to many reasons such as insulation, cost and safety issues, high voltage is not preferred in electronics. However, large air flow comes from large piezo fan amplitude, and the amplitude comes from high electric field. Here, we decreased the thickness of piezoelectric element to increase the electric field at the same voltage at first. Then, we laminated the thin piezoelectric elements to increase the generated force and attached the laminated elements to the blade. Table shows the performance of two piezo fans with the same geometric configuration and indicates the effectiveness of decreasing the driving voltage.

3. Long life and robust piezo fan

Figure 1(b) shows a typical piezo fan comprising a piezoelectric element and a blade made from thin sheet. However, this structure works but has problems in life test because the inertial force of the blade tip applies large moment to the piezoelectric element. Especially, large stress appears around the free end of the piezoelectric element. As a result, the blade gets detached from the piezoelectric element in a long-term test. Moreover, the inertial force becomes very large when foreign objects come in contact with the moving piezo fan and, thus, detachment occurs frequently in this condition. Also, the adhesive connecting the piezo and the blade tends to lose its adhesion force. Thus, the detachment occurs especially frequently in high-temperature environment.

Figure 3 shows our solution. Figure 3(a) shows the traditional structure of piezo fan and indicates the position where stress concentrates. We relaxed the concentrated stress by putting a supporting block as shown in Fig. 3(b).

Figure 4 shows the result of the FEM results by using ANSYS®. For convenience of explanation, the

Table. Comparision of single-and multilayer piezo fan.

Structure	Driving voltage	Resonant frequency	Vibration amplitude	Consumption power
Single-layer piezo fan	65 V_{pp}	46 Hz	26 mm	7 mW
Multilayer piezo fan (10 layers)	6.5 V_{pp}	41.5 Hz	25 mm	6 mW

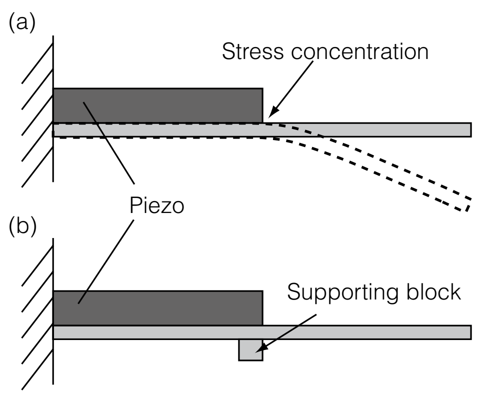

Fig. 3. The structure of the long-life piezo fan.

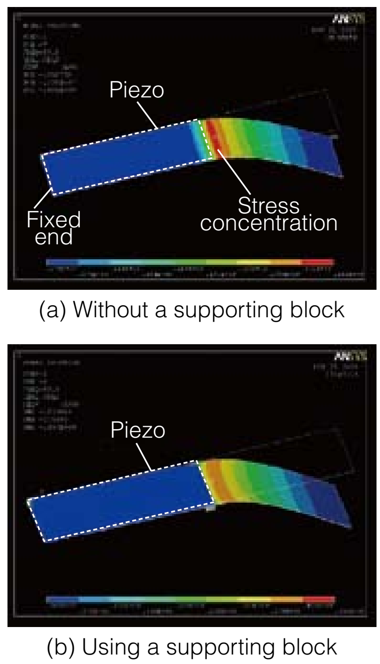

Fig. 4. Stress analysis of a piezo fan.

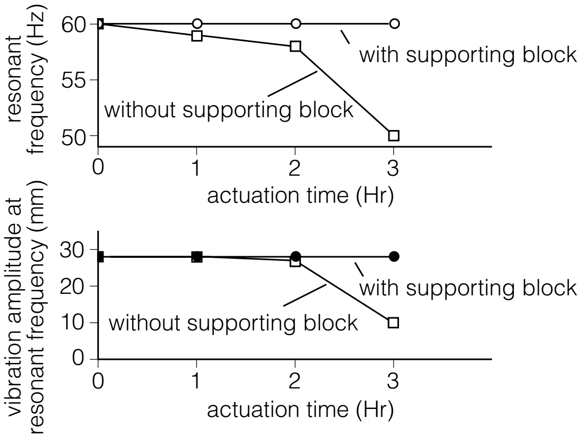

Fig. 5. Performance change of a piezo fan in a high-temperature environment.

piezoelectric element is set to be invisible and its contour is marked by dotted lines. Figure 4(a) and (b) shows the Von Mises stress while the blade has the maximum displacement at its first resonance. The structure in Fig. 4(b) uses the same structure shown in Fig. 3(b). It is clear that large stress exists around the free end of the piezoelectric element and the stress is supported by adhesive only. It is considered that the blade detaches from piezoelectric element when the adhesive force decreases or when external force causes the concentrated force to increase. Figure 4(b) using the structure with a supporting block shows that the concentrated stress relaxes a lot, but the displacement is almost the same. Also, although not shown in the figure, the maximum displacement and stress of the piezoelectric element itself also decreases in the structure with a supporting block. This means that this structure can also help to prevent the crack generation on the piezoelectric element.

Figure 5 shows the test results of piezo fans under 100 °C environment. The piezo fans had 60 Hz resonant frequency at first. However, as shown in the figure, the resonant frequency of the piezo fans without supporting blocks changed in this test. At the same time, the displacement also decreased while actuating these piezo fans by the resonant frequency. On the contrary, those piezo fans with supporting blocks kept the performance even when the adhesive force decreased at high temperature. In another test, piezo fans were set in a high-temperature and high-humidity environment (60 °C,65%). In this test also, piezo fans retained the performance after more than 10^9 times the vibration (30 mm amplitude, 60 Hz).

4. Electronics cooling of piezo fans

4.1. Portable electronics cooling of piezo fans

One characteristic of portable electronics cooling is that multiple cooling objectives exist, but heat flow of

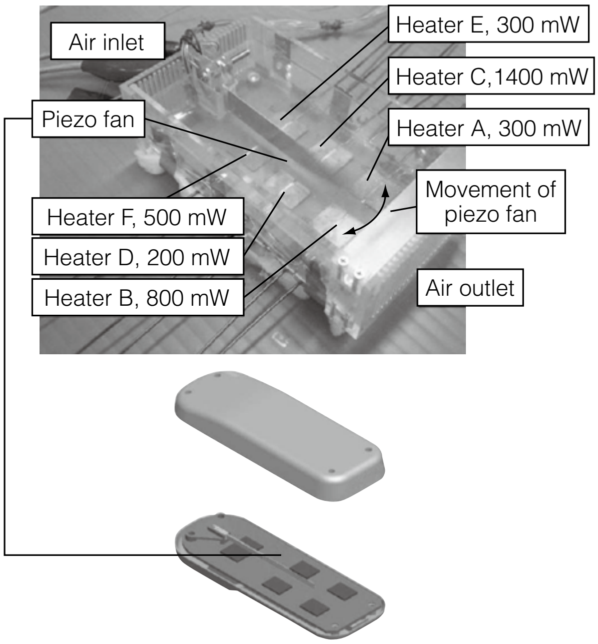

Fig. 6. Piezo fan application in portable electronic devices (imaginary picture) and the experiment setup based on a real portable electronic device IC design.

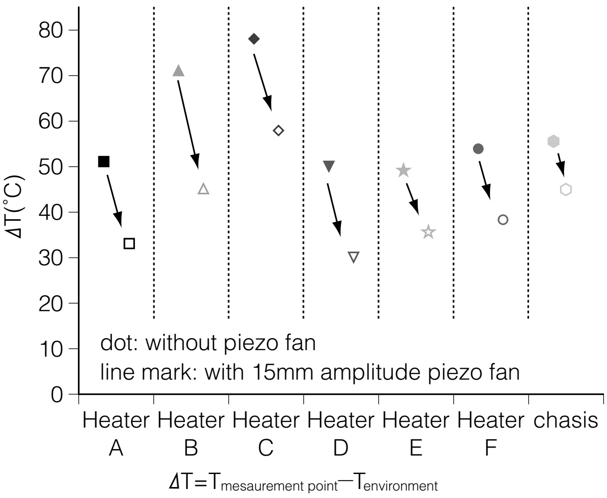

Fig. 7. The cooling effect of piezo fan in a portable electronic device.

each heat source is much lower than that in PC. The point is that the thermal management must be based on low consumption power and low noise at close range.

Figure 6 shows the image of piezo fan cooling in a portable electronic apparatus and the experiment apparatus. The layout and heat flow is based on a commercial product. In the experiment, we tested 3, 5, 7, 10 mm width piezo fans. In Fig. 7, ΔT (°C) is the temperature difference between heat sources surfaces and environment, and the chassis internal space and environment while using the 3 mm width piezo fan. The temperature at all measured points decreased from 10 to 20 °C. It is noted that the temperature decreases around the free end of the piezo fan (heat sources A, B, C, D) showed the same trend in Açıkalın's[2) 3)] report. The temperature decreases around the fixed end of the piezo fan (heat sources E, F) and the change in the chassis further proved the effects of air suction and exhaustion. The 3 mm width piezo fan that cleared the target cooling performance was also satisfactory in other aspects. The noise of the 3 mm width piezo fan was 24 dBA (10 mm apart from the chassis) and that of the 5 mm piezo fan was 29 dBA. The power consumption of the 3 mm width piezo fan was 11 mW, about 1/20 that of the axial fan or the blower with the same cooling performance.

4.2. LED modules cooling

Life and brightness of LED tends to decrease much as the temperature increases. This is especially an important issue for high-brightness LED because it generates much more heat. Figure 8 shows a piezo fan cooling module designed for a backlight module with multiple LED modules. The cooling targets were five heat sources each with 10 W heat flow on the heat spreader. The design uses piezo fan to induct air flow from one end of the long and thin heat sink to the other. The piezo fan and the fins were set to be very close, so that movement of the fan can decrease the thermal boundary layer thickness and improve the thermal resistance. We think these are the reasons why this cooling module decreased the size to 50% compared to that of the current model (thermal resistance decreased from 4.4 °C/W to 2 °C/W) and kept the temperature variation on each heat source to below 1 °C.

4.3. Low-cost, compact-sized PC cooling

Low-cost PC is considered to be a very potential market. The heat flow of the low-cost PC CPU is about 20–30 W lower than that of the normal PC and thus the demand for cooling module is reduced. Figure 9 shows an example of the CPU cooling module using piezo fan. We set slits on the blade and inserted it into to the gap between the fins. Movement of the blade in this design can decrease the thermal boundary thickness layer to improve the cooling ability of the heat sink. The appearance of the blade is similar to a rake and is thus named raked piezo fan. One advantage of this design is that all the blade tips have the same resonant frequency and, thus, the same vibration amplitude by actuating one piezoelectric element. Another advantage is that the blade is inside the heat sink. This means that the manufacturer can have a simple assembling process and the user can have a compact cooling module.

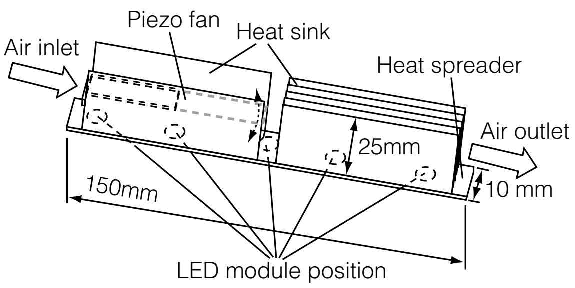

Fig. 8. Piezo fan application in LED modules cooling.

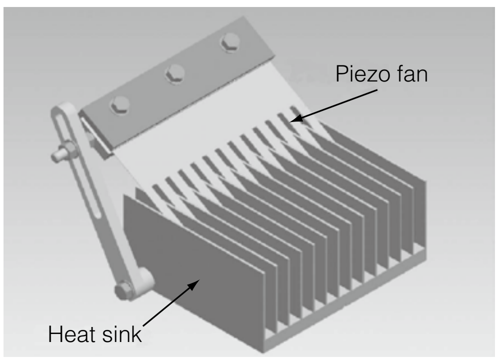

Fig. 9. Raked piezo fan.

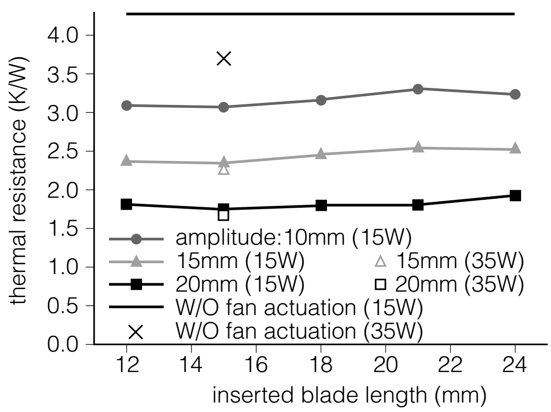

Fig. 10. Cooling effect of raked piezo fan.

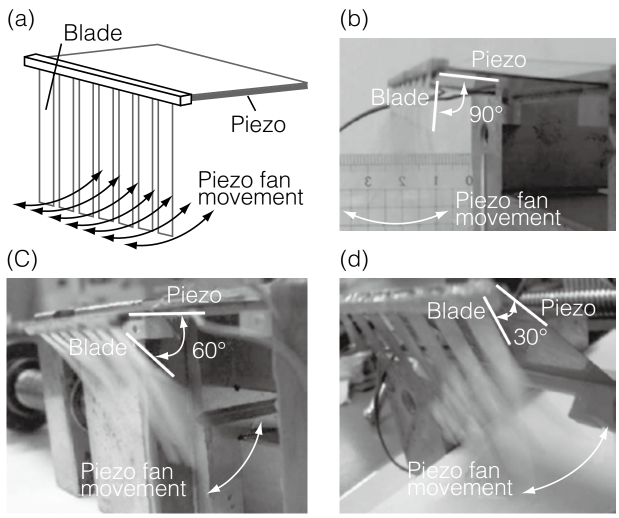

Fig. 11. Compact-type piezo fans.

Figure 10 shows a test result by using the raked piezo fan. The heat sink used in the experiment had a size of 50 × 50 × 35 mm and had eight fins. The piezoelectric element was set to be parallel to the bottom side of the heat sink. The results show that to reach the target thermal resistance of 2.7 K/W, only 15 mm amplitude was necessary. By increasing the amplitude, it was even possible to decrease the thermal resistance to half of the target value.

Although the cooling module becomes more compact by inserting the blade into the heat sink as shown in Fig. 9, we think that it is still necessary to have a more compact design because compact size is the current trend in PCs. After thoughtful consideration about the energy transmission, we succeeded to keep the same amplitude even when the piezoelectric element and the blade are not parallel. Figure 11 shows one of the designs. In this design, the blade can be set inside the heat sink and the piezoelectric element can be set parallel to the heat sink bottom. Nothing protrudes out of the heat sink in this design and thus the cooling module becomes even more compact.

5. Conclusion

Piezo fan was developed and tested in order to satisfy the demands of light-weight, low noise and power, and compact-sized computer, portable electronics, and LED-mounted electronics. On the way to commercialization, the life and robust issues have been resolved so far. Also, by designing heat sinks that fit properties of piezo fan, we proved that other than its inherent advantages, the piezo fan cooling modules have better cooling performance than current cooling modules. Now we are moving toward commercialization with the mass production technology development.

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