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The effects of the temperature on the Ultrasonic transducers

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Nowadays difficult-to-cut materials are widely used in industrial products such as automobile parts or aerospace parts. Thus, ultrasonic-assisted machining comes into the limelight for machining difficult-to-cut materials. Ultrasonic-assisted machining is a process that uses high-frequency vibration to the cutting tool to enhance the cutting force and surface integrity. The most important part of an ultrasonic machine device is the transducer, which generates ultrasonic vibrations. A high-frequency electrical signal is transformed into vibration motion in the ultrasonic transducer. However, during this process, heat is generated from the piezoelectric. The vibration amplitude of the ultrasonic transducers is reduced by this heat generation, which also changes the resonance frequency. Therefore, it needs a coolant when operating the ultrasonic transducer. The heat transfer in the operational condition of the ultrasonic transducer is examined in this paper with an infrared camera. Compare the conditions with and without coolant as well. Additionally, when the piezoelectric is in a high-temperature state, use an impedance analyzer to find the change in resonance frequency. The resonance frequency decrease by 0.91 % and the amplitude decreases by 32.9 % as the temperature reaches 70°C.

NOMENCLATURE

F_r = Resonant frequency
d_{33} = Charge Constant ($10^{-12} C/N$)
k_{33} = E-Mech Coupling

1. Introduction

Difficult-to-cut materials are widely used in the manufacturing process, such as power plant parts or aerospace parts. However, when machining difficult-to-cut materials, intense thermal damage occurs along the tool's cutting edge, rapidly reducing tool life. [1] This heat damage also contributes to the work piece's poor surface integrity. [2] Ultrasonic-assisted machining is one of many industrial techniques that can solve these problems. The piezoelectric, which generates the ultrasonic vibration, is the essential component in ultrasonic-assisted machining. The piezoelectric converts the electrical signal into vibration motion. This process results in energy loss and heat production. The vibration's amplitude is reduced by the heat generated, which also changes the system's resonance frequency. [3,4] Therefore, a coolant, such as air or oil, must be used during the ultrasonic-assisted machining process. Furthermore, in order to optimize the amplitude of the ultrasonic vibration, the resonance frequency change must be tracked. In this research, a thermal imaging camera is used to analyze heat transport on the ultrasonic transducer. In addition, investigate how the amplitude and resonant frequency change as the temperature rises.

2. Experimental setup

2.1 Ultrasonic transducer

Fig. 1 shows the design of the transducer for ultrasonic-assisted milling. The four PZT-4 piezo-electrics are used in the transducer. Table. 1 shows the properties of piezoelectric. The transducer is made of titanium alloy, which has excellent acoustic properties. [5] Fig. 2 shows the modal analysis result of the transducer. The transducer's resonance frequency is 27.919 kHz, as shown by the results.

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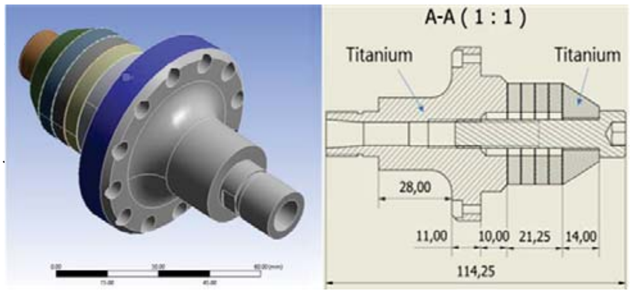
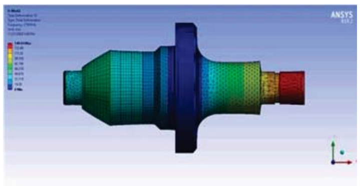


Fig. 1 Design of ultrasonic transducer



$F_r = 38.889\ kHz$

Fig. 2 Modal analysis of transducer

Table 1 Properties of piezoelectric PZT-4

Property	Symbol	value
Relative permittivity	$\varepsilon^{T}_{r\,33}$	1650
Dissipation Factor	$\tan\delta$	0.0030
E-Mech Coupling	k_{33}	0.71
Charge Constant ($10^{-12}C/N$)	d_{33}	372
Voltage Constant ($10^{-3}Vm/N$)	g_{33}	25.5

2.2 Heat transport of ultrasonic transducer

Fig. 3 and Fig. 4 shows the experimental setup for analyzing the heat transport on the ultrasonic transducer. The input voltage was 300 V peak to peak value, and the ultrasonic frequency was 38.88 kHz. Each of the two test states—"with coolant" and "without coolant"—was operational for 30 minutes. In addition, the air from the air compressor is used for coolant.

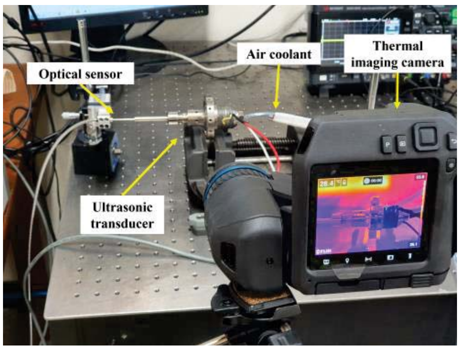


Fig. 3 Experimental setup for analyzing temperature 1

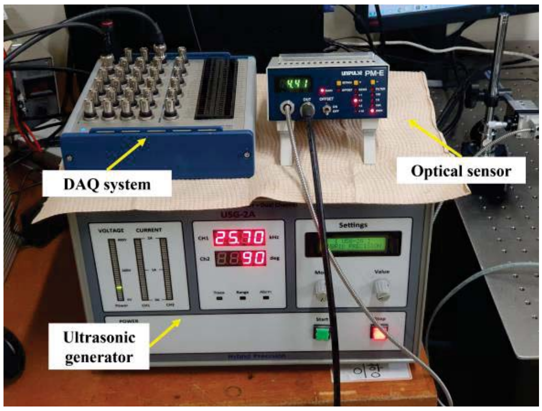


Fig. 4 Experimental setup for analyzing temperature 2

2.3 Resonant frequency change

The experimental setup for analyzing how the resonant frequency and amplitude changes as the temperature of the piezoelectric surface increases is shown in Fig. 5. For each 10 °C increase in temperature, the resonant frequency was measured.

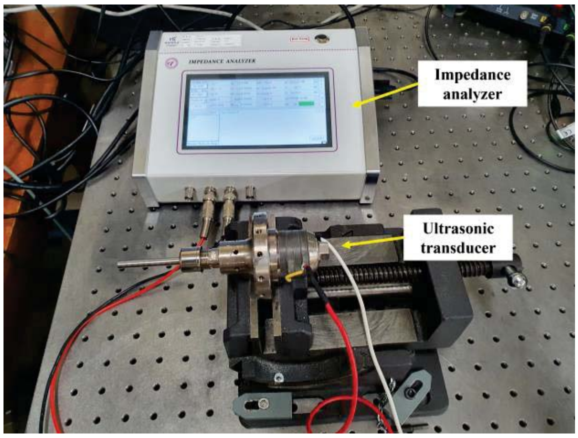


Fig. 5 Experimental setup for analyzing resonant frequency

3. Results

3.1 Piezoelectric surface temperature change

Fig. 6 shows the temperature of the piezoelectric surface according to the coolant states. With coolant, the temperature only increased by about 5 °C and converged at about 27 °C. Without a coolant, however, the temperature reaches over 65 °C. Additionally, the temperature is raised by nearly 2.5 °C/min within the first 10 minutes of operation. As a result, applying coolant can decrease heat generation by around 60%.

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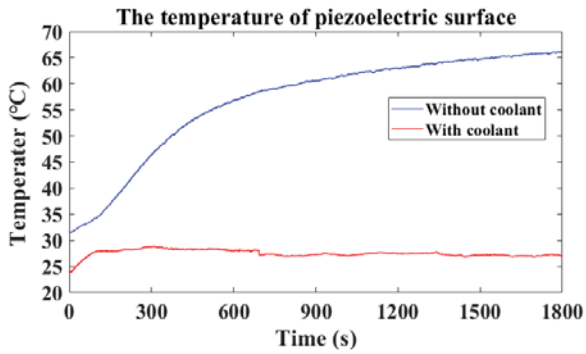

Fig. 6 The temperature change of piezoelectric surface

3.2 Resonant frequency change

The Impedance angle relation to temperature increase is shown in Fig. 7. As a result, the impedance angle at 30 °C and 40 °C are similar. However, between 25 kHz and 32.5 kHz, the impedance angle increase is reduced at 50 °C, 60 °C, and 70 °C. Additionally, at 60 °C and 70 °C, there is an additional impedance angle shift added over the 35 kHz.

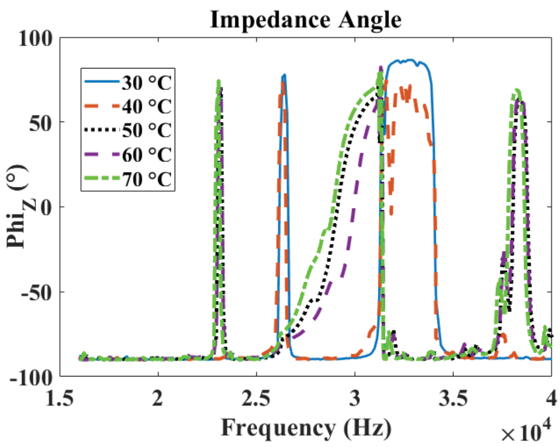

Fig. 7 The impedance angle change according to temperature

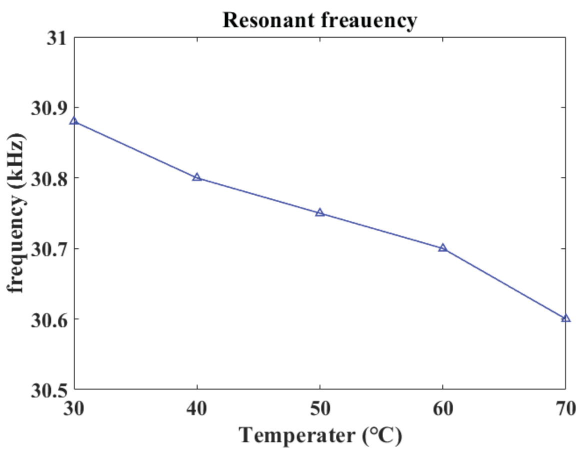

Fig. 8 Resonant frequency change according to temperature

Fig. 8. Shows how the increase in piezoelectric surface temperature changes the resonant frequency. As a result, as the temperature increases, the resonance frequency continues to decrease. Additionally, compared to 30 °C, the resonant frequency was only dropped by 0.91% at 70 °C.

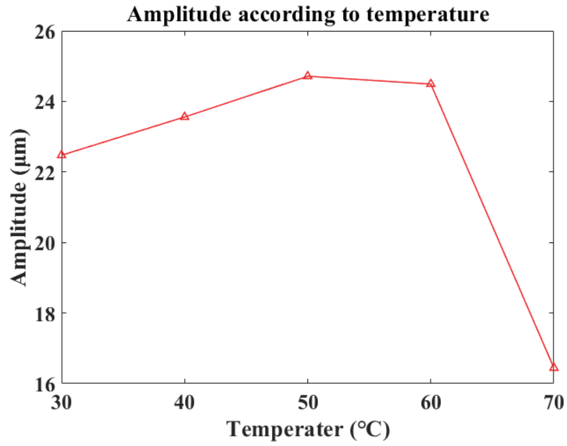

Fig. 9 Amplitude change according to temperature

The amplitude of the ultrasonic transducer with temperature increase is shown in Fig. 9. As a result, the amplitude increases until the temperature reaches 50 °C, the highest amplitude is recorded with a value of 24.49 µm. Between 60 °C and 70 °C, the amplitude, however, shows a significant reduction of about 32.9%.

3. Conclusions

Based on the results, using an ultrasonic transducer without a coolant leads to a temperature increase of more than 65 °C. Therefore, coolant is important that can reduce heat generation by about 60 %.

The parameters of the piezoelectric, which include impedance angle, resonant frequency, and amplitude, also change as the temperature rises. As a result, as the temperature increases, the resonance frequency is reduced. In comparison to 30 °C and 70 °C, the decline rate was 0.91%. Therefore, to operate the ultrasonic transducer, it must determine the proper frequency based on the piezoelectric temperature.

As a result, under 60 °C, the ultrasonic transducer's amplitude changes by around 8.98%. At 70 °C, however, the amplitude shows a significant reduction of about 32.9%. According to result, the piezoelectric function has a critical temperature. Therefore, it must be prohibited that the ultrasonic transducer operates at the critical temperature.

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