Special Interest Group meeting
Thermal Issues
Eindhoven, The Netherlands, March 2024
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Ultrasonic Thermometry for Manufacturing Materials Using the Pulse-Echo Method

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Abstract
Core temperature of workpieces during manufacturing processes can vary significantly from the surface temperature. If the thermally induced expansion of the workpiece is estimated using the surface temperature, it may lead to a wrong estimation resulting in over or under-compensation for the effects of thermal expansion. Ultrasonic thermometry has been shown to measure the core temperature of steel sample of 100 mm (EN24T) with a resolution and accuracy of better than 0.5 °C and ±1 °C[1]. This study establishes the suitability of ultrasonic thermometry for other metals namely brass, stainless steel, aluminium, and mild steel. By using a calibrated temperature bath, the ultrasonic time-of-flight for different metals was measured. This was done to establish the relationship between the materials and the ultrasonic time-of-flight (TOF) in them at different temperature. The model that will be created using this measurement method can be used during dimensional inspection or subtractive manufacturing processes to aid the control or compensation for the effects of temperature change.

Ultrasonic thermometry; pulse-echo method, core temperature measurement

1. Introduction

During manufacturing processes such as milling, the heat generated at the tool-workpiece interface may cause the workpiece temperature to be inhomogeneous, this often means that the surface of the workpiece is hotter than its core. Temperature inhomogeneity can also be encountered during dimensional measurement especially in cases where the workpiece has not been allowed to fully reach the ambient temperature. Since existing temperature measurement devices can only indicate the surface temperature, the measured value may not truly represent the workpiece volume especially in large workpieces. Ultrasonic thermometry has been used to measure the core temperature of steel (type EN24T) during dimensional measurement and subtractive manufacturing. The results show that the measurement can be done with a resolution and accuracy of better than 0.5 °C and ±1 °C which agrees with the initial simulations [2–4]. The temperature-ultrasonic velocity relationship differs for different materials, hence, there is a need to establish this relationship for other materials. This study presents the experimentation and analysis of the ultrasonic thermometry results which will be used to create a model for the materials of interest.

2. Materials and methods

Ultrasonic phase-shift method has been used for core temperature measurement in previous research [4]. The main limitation of the method is the inability of the employed electronic device to handle high voltage single. This makes measurement of larger workpieces difficult due to the significant attenuation of the ultrasonic signal. Pulse-echo devices can generate and receive higher voltage signals. The signal for the pulse-echo method used in this study was generated using Tribosonic xScan (Tribosonic Ltd., Sheffield, UK). The xScan generates pulses of up to 90 V which aids the penetration of larger workpieces. An ultrasonic thermometry experiment was carried out for four different materials, namely CZ121 Brass, 316 Stainless steel, EN1A(230M07) Mild steel, and 6060-T66 Aluminium. These materials were chosen because of their prevalence in precision manufacturing. Using the setup shown in Figure 1, a liquid bath calibrator was used to control the temperature of the workpieces by changing the set temperature in steps of 1 °C and 0.1 °C. The ultrasonic time of flight was measured with the xScan, and the reference temperature was measured with a PT100.

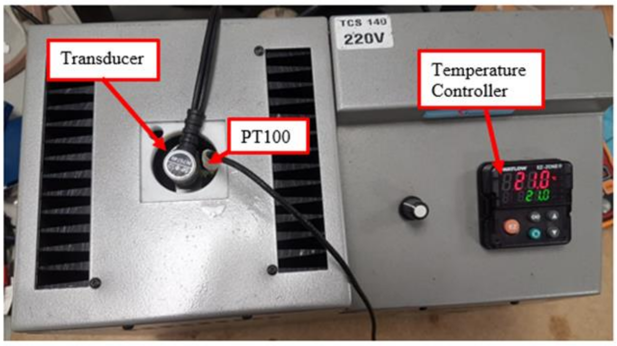

Figure 1. Ultrasonic thermometry setup using a liquid bath calibrator.

The results of the experiments are presented in section 3.

3. Results and Discussion

The PT100 and the TOF results for aluminium of nominal length of 150 mm are shown in figure 2. The TOF measurements were filtered and converted to temperature values as shown in figure 3. The differences between the ultrasonic thermometry measurements and the bath's set points were calculated, this was also done for the PT100 results, this is shown in figure 4.

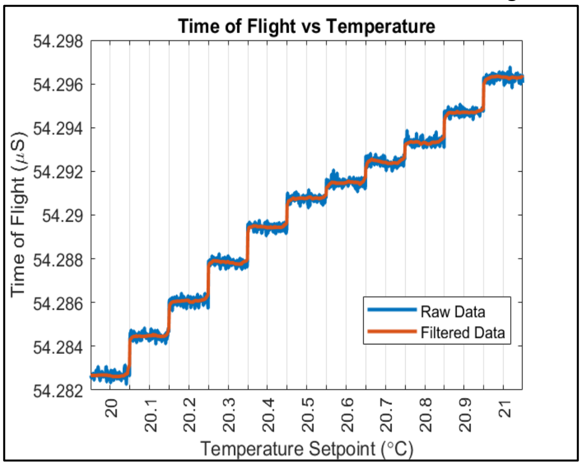

Figure 2. Raw and filtered Ultrasonic TOF data.

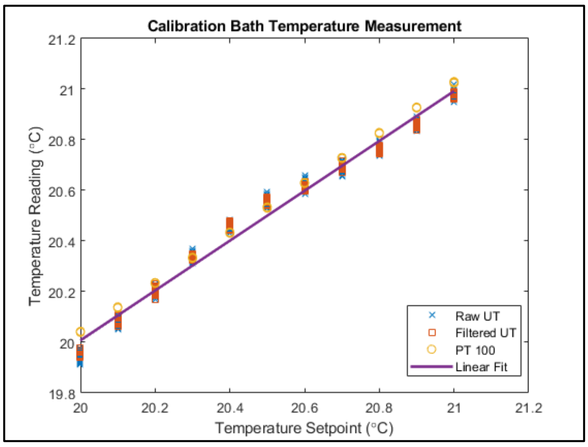

Figure 3. Ultrasonic thermometry and PT100 data.

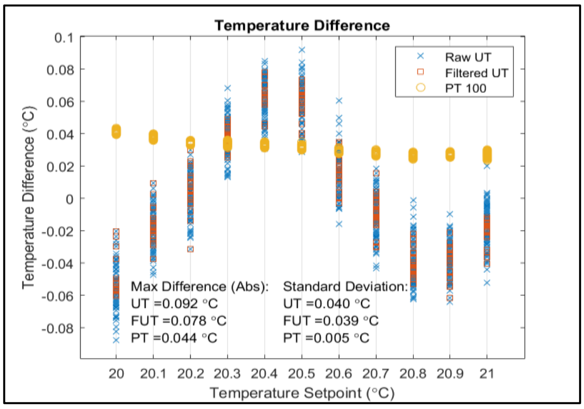

Figure 4. Deviations of the measurement results from the setpoint.

Table 1 shows the deviations of the measurement results from the setpoint for all the materials in a 1 °C step experiment.

Table 1. Deviations of the results for all tested materials

Result		**Max Difference (°C)**	**Std. Deviation (°C)**
Material	Mild Steel	0.251	0.097
	Stainless Steel	0.264	0.124
	Brass	0.205	0.086
	Aluminium	0.105	0.062

4. Conclusion and Future Work

This study shows that ultrasonic thermometry can be used for multiple manufacturing materials using the time-of-flight method. In all the experiments, the maximum deviation from the setpoint is less than 0.27 °C with a maximum standard deviation of 0.124 °C. Future work will explore the creation of an ultrasonic thermometry model for different materials at different lengths with the possibility of ultrasonic thermometry coefficient generation when the material's physical properties are known. This will enable a quick calibration and use of the device and method for other materials during manufacturing processes.

References

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