Remote Temperature Sensing System Using Reverberated Magnetic Flux

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Remote Temperature Sensing System Using Reverberated Magnetic Flux

Y. H. Kim, S. Hashi, K. Ishiyama, K. I. Arai, and M. Inoue

***Abstract*—A remote temperature sensing system was investigated. The system can measure the temperature by applying an external magnetic flux to the sensor and by receiving a flux at the resonant frequency corresponding to the temperature at the sensor. The sensor does not need a power supply within it and is only composed of a temperature sensitive ferrite core and a wound coil. The inductance of the core varied from about 8–18 mH in the temperature region of 35–55°C. The induced voltage, ΔV by the sensor was about 10 mV for a 260 mm length between the transmitter and receiver. The system was successfully operated in our investigation.**

***Index Terms*—Curie temperature, magnetic flux, remote sensing, temperature sensing system, temperature sensitive ferrite.**

I. INTRODUCTION

TEMPERATURE measurement has been performed by using the temperature characteristics of magnetic properties. It is well known that the permeability, the coercive force and the saturated magnetization of a ferrite with low Curie temperature varies sharply with temperature near its Curie temperature. Using the temperature dependence of the properties, temperature sensing systems have been developed [1]–[3]. Remote temperature measurement is very important and necessary at an isolated place such as inside a human body. For this application, the sensor needs to be as small as possible. Though remote temperature sensing has been investigated using a ferrite with low Curie temperature [4], [5], the size of the sensors was large because they required a power supply circuit.

We investigated a remote temperature sensing system. The system can measure the temperature by applying an external magnetic flux to the sensor and by receiving a flux of the resonant frequency corresponding to the temperature around the sensor. The sensor does not need a power supply within it and is composed of the temperature sensitive core and a wound coil only.

II. EXPERIMENTALS

Fig. 1 shows the photograph of the sensor used in this experiment. The sensor was composed of 12 ferrite ring cores and one bar-type ferrite. The ring core had a low Curie temperature and its permeability changed rapidly in the temperature region of 35–50°C. The sizes of ring core and bar-type ferrite are $4\ \text{mm}\phi \times 2\ \text{mm}$ and $1.8\ \text{mm}\phi \times 18\ \text{mm}$, respectively. The bar-type ferrite was inserted through the ring cores to increase the inductance of the sensor core. The bar-type ferrite had no influence on the inductance change since its Curie temperature was higher than that of the ring core. The ferrites were placed within a glass tube with wound coil of 800 turns. There was a stray capacitance of the coil, 55.3 pF. Therefore, the sensor is represented as a series circuit of inductance L and capacitance C.

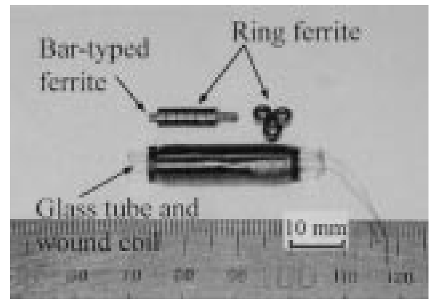

Fig. 1. Sensor for temperature measurement.

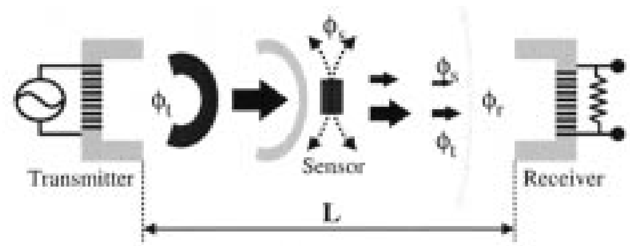

Fig. 2. Explanation for the remote temperature sensing.

Fig. 2 represents the method for remote temperature sensing. The magnetic flux ϕ_t was generated from the transmitter. The sensor was magnetized by the flux and the sensor generated the magnetic flux ϕ_s having a peak at the LC resonance frequency, f_o. Due to both magnetic fluxes reaching the receiver, a voltage was induced and measured in the receiver. The received magnetic flux ϕ_r is the sum of ϕ_t and ϕ_s as shown in (1) and has the maximum value at resonance frequency f_o. The induced voltages V and ΔV can be defined as (2) and (3), respectively. In this equation, n is the number of coil turns.

$$\phi_r = \phi_t + \phi_s \tag{1}$$

$$V = -n\frac{d\phi_t}{dt} \tag{2}$$

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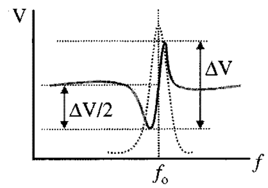

Fig. 3. Schematic illustration of the induced voltage in the receiver.

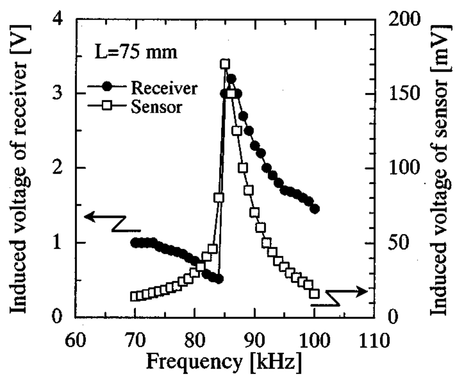

Fig. 4. Induced voltage of receiver and sensor.

$$\Delta V = -\,n\,\frac{d\phi_s}{dt} \tag{3}$$

$$f_o = \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

Fig. 3 is a schematic illustration of the induced voltage in the receiver. If the sensor is not in place, no changes of the induced voltage will appear. On the contrary, when the sensor is in place, the change of the induced voltage will appear as a solid line in Fig. 3. In this investigation, the resonance frequency of the sensor was defined by $\Delta V/2$ as shown in the figure. The resonance frequency agreed with the calculated resonance frequency of LC circuit.

If the inductance of the sensor changes with the temperature, the resonance frequency will vary. The temperature around the sensor could be measured by measuring the frequency of $\Delta V/2$ in the receiver.

The sensor was placed into a beaker which was filled with hot silicon oil above 60°C. The silicon oil cooled very slowly by natural cooling. The sensor was located the center between the transmitter and receiver. A pair of cut cores was used as a transmitter and a receiver, respectively. The size of cut core is 80 mm × 40 mm and the cross section area is 177 mm^2. The transmitter was excited with constant 60 V_{rms}. The induced voltage was measured to investigate the magnetic field applied to the sensor by using air coil. The air coil was also located at the center between the transmitter and the receiver. In the frequency region of 150–250 kHz, the magnetic field was about 0.05–0.02 Oe.

III. Results and Discussion

Fig. 4 shows the voltages measured at the sensor and at the receiver. The distance between the transmitter and the receiver was 75 mm. The peak voltage of the sensor occurred at 85 kHz and the frequency agreed well with the frequency of $\Delta V/2$ in

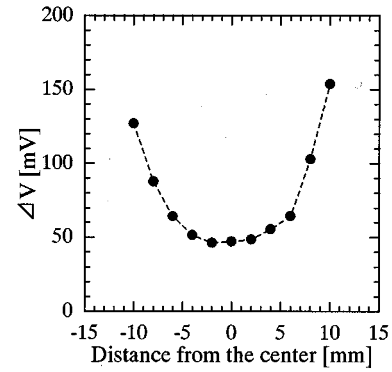

Fig. 5. Dependence of ΔV on sensor location.

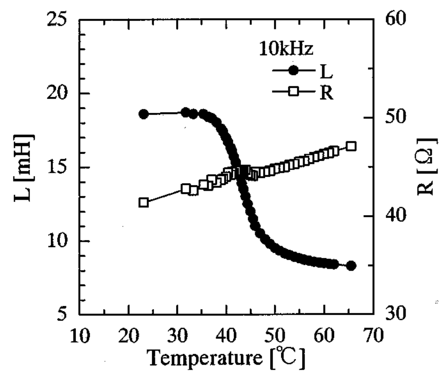

Fig. 6. Temperature dependence of L and R.

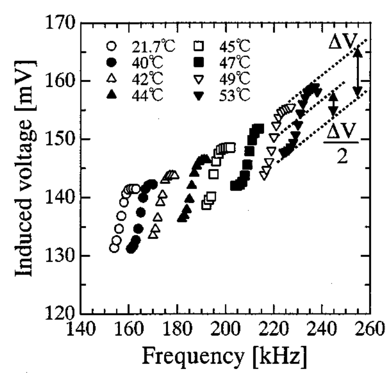

Fig. 7. The frequency dependence of induced voltage.

the receiver. Fig. 5 shows the dependence of ΔV on the sensor position between the transmitter and the receiver. The ΔV was the lowest at the center between the transmitter and the receiver. Fig. 6 shows the dependence of L and R on temperature for the sensor. As the temperature was close to the Curie temperature of the ferrite, the inductance L sharply decreased while the resistance R increased monotonically. Above 50°C, the sensor had a inductance only about 8 mH due to the inductance of the bar-type ferrite and air coil. Fig. 7 shows the dependence of the induced voltage on the frequency for different temperatures. This experiment was carried out with the distance between the transmitter and the receiver of 260 mm. The ΔV induced by ϕ_s was about 10 mV and the V induced by ϕ_r monotonically increased. Fig. 8 shows the dependence of the resonance

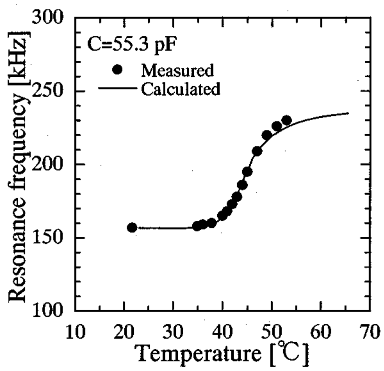

Fig. 8. Dependence of resonance frequency on temperature.

frequency on the temperature. The resonance frequencies were calculated by (3). In the calculation, the inductance of Fig. 6 and the stray capacitance, 55.3 pF were used as L and C in (4), respectively. Since the inductance of the sensor decreased with increase of temperature in the vicinity of the Curie temperature, the resonant frequency increased as the temperature increased. The measured resonance frequency agreed well with the calculated ones. From these experimental results, it was clarified that the remote temperature sensing system was successfully operated.

IV. Conclusion

The remote system can measure the temperature by applying the external magnetic flux to the sensor and by receiving the flux of the resonant frequency corresponding to the temperature around the sensor. The sensor does not need the power supply within the sensor and this system is only composed of the ferrite cores and the wound coil. The inductance of the core varied about 8–18 mH in the temperature region of 35–55°C. The induced voltage, ΔV by the sensor was about 10 mV for a 260 mm distance between the transmitter and receiver. The measured resonance frequencies agreed well with the calculated ones at each temperature. Therefore, the system was successfully operated in our investigation.

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