The Study of Self-Heating Errors on 100 ohm Platinum Resistance Thermometers

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Platinum resistance thermometers (PRTs) are widely used in many fields of industrials because it is significantly accurate compared with other types of thermometers. Although the PRTs are very accurate, there are few errors occurred in PRT measurement, for example, errors due to an immersion depth, a long term drift and a self-heating. In this study, self-heating error is of interest for the PRTs. Self heating is the phenomenon that caused by the power dissipated and accumulated in the element, resulting in the increase of element temperature to be higher than the surrounding temperature. As a result of this, there will be an error from the self-heating, which is always happened and very difficult to avoid in the measurement results. In this research, the self-heating errors of the 100 ohm PRTs are investigated. Three parameters that could affect the self-heating error are studied: sensing currents, measured temperatures and probe dimensions. The ratio of the couple current used to obtain the self heating error is 1:√2 and the sensing currents are varied from 0.5 mA to 2 mA. The measured temperatures are 0 °C, 23 °C, 150°C and 300 °C. In this study, there are 5 different types of 100 ohm PRTs. It was found that the higher the sensing current, the larger the self-heating error occurs. However, the sensing current of 0.5 mA resulted in instable measurements, whereas the current of 1 mA caused the least self-heating error (less than 10 mK at 300 °C) with sufficiently stable results. The measured temperature and the probe dimension were found to have less effect on the self-heating errors. Additionally, the medium where the PRT is immersed has been shown up to be more influential in the self-heating errors. From the study, the medium with less thermal conductivity caused more self-heating error.

Keywords: Self heating error, Platinum resistance thermometer

1. INTRODUCTION

Platinum Resistance Thermometers (PRTs) are devices used to measure temperature by correlating resistance with temperature; the change in resistance is depending on the temperature, the higher the temperature, the larger the resistance. To measure the resistance, the electrical current is required to pass through the sensing element and the voltage drop across the resistance is observed to obtain the resistance.

PRTs are widely used in many fields of industrial due to low cost, compared with Standard Platinum Resistance Thermometers (SPRTs). Additionally, they have relatively high accuracy, compared with other type of thermometers: thermocouple, digital thermometer, and liquid in glass thermometers. Although they are very accurate, there are a few errors occur in the PRTs measurement. One of the major causes to the errors is the self-heating effect. The self-heating effect is a well known phenomenon that occurs when sensing current heats up the PRTs sensor, [1, 2]. As a result of this, the reading temperature is slightly higher than the actual temperature. For a very high accuracy measurement, SPRTs, the self-heating errors is typically 0.2 – 3 mK , [3], and for PRTs 100 Ω, it can be up to 50 mK, depending on many factors, [1, 4, 5].

In this paper, the self-heating background is presented and the factors influencing the self-heating errors are investigated on the 5 different types of PRTs 100 Ω in order to estimate and reduce the self-heating errors by obtaining the optimal conditions for PRTs 100 Ω measurements.

1.1 Self-Heating Background

Self-heating effect occurs when the sensing current dissipates power and increases the temperature of the sensing element. The self-heating error is directly proportional to the square of the sensing current. The current, I, dissipates power, P, the self-heating error can be directly calculated in term of temperature by the following equation, [6];

$$\Delta T_{SH} = \mathrm{Pr} = I^2 Rr \qquad (1)$$

ΔT_{SH} is the self-heating error, R is the resistance and r is the thermal resistance, which can be divided into two parts; one is the thermal resistance from the PRTs coil

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to the sheath and the other one is the thermal resistance from the sheath surface to the ambient. Therefore, the thermal resistance is dependent on the PRT Design and the medium in which the PRT is immersed. However, these two thermal resistances are very difficult to obtain; the two currents method is introduced, [7].

To obtain the self-heating error, two different currents are used to measure temperatures and the self-heating error can be calculated accurately to better than 1% for PRTs 100 Ω from the following equation, [4];

$$\Delta T_{SH1} = (T_2 - T_1)[I_1^2/(I_2^2 - I_1^2)] \qquad (2)$$

ΔT_{SH1} is the self-heating error at current I_1 and T_1 and T_2 are the temperature at I_1 and I_2, respectively. The most commonly currents used are 1 mA and √2 mA because they make equation (2) very simple and the optimal uncertainty of the self-heating error is at a certain pair of currents; 1.5 mA and 2.5 mA, [7]. The self-heating effect is always happened and it cannot be eliminated; however it could be corrected with some uncertainty by using equation (2).

1.2 Factors Influencing Self-Heating Error

There are many factors that could affect the self-heating error; PRT design, sensing current and surrounding medium; therefore, if the optimal conditions of these factors can be obtained, then the self-heating error could be reduced.

PRT Design

The different PRT designs could result in different self-heating error. If the PRT has a large surface area of the sensing element, the heat generated can be dissipated more to the surrounding medium than the PRT with a small surface area. Additionally, the size of the sheathing could also affect the error; the smaller the sheathing, the larger the error occurs.

Sensing Current

As can be seen from equations (1) and (2), the temperature error due to the self-heating effect is increased with the square of the current; thus the sensing current needs to be considered when using the PRT. The conventional current used is typically 1 mA for PRT 100 Ω, recommended by the manufacturer.

Surrounding Medium

A medium, in which the PRT is immersed, also plays an important role in the self-heating phenomenon. The highly thermal conductivity medium could help more heat to be dissipated. In addition, the self-heating error decreases with the increase of the flow rate of the moving medium, [6]. However, the temperature of the medium could also affect the error because it will alter the properties of the medium.

2. EXPERIMENT

In an investigation, there are 5 different types of PRT 100 Ω; Table 1 shows details of each probe used.

Table 1: Details of each PRT 100 Ω

Model	Length	Diameter
5626	38 cm	6.40 mm
5627	30 cm	6.40 mm
STS100A500	50 cm	4.00 mm
Pt 100	53 cm	5.95 mm
TS32A	49.5 cm	3.20 mm

There are three parameters that had been studied in this research; sensing currents, measured temperature and probe dimensions. The ratio of the couple currents used to obtain the self-heating errors is 1:√2 and the sensing currents were varied from 0.5 mA to 2 mA by 0.5 mA each step. The measured temperatures are 0 ˚C, 23 ˚C, 150 ˚C and 300 ˚C. These measured temperatures could not be done by using one temperature source. Therefore, the alcohol bath was used to set the temperature of 0˚C and 23 ˚C. For higher temperatures, the oil bath and the dry block were used to set the measured temperatures of 150 ˚C and 300 ˚C, respectively. Then the self-heating errors are calculated based on equation (2) and the results are presented and discussed in next section.

3. RESULTS AND DISCUSSIONS

First of all, the sensing currents were varied at each measured temperature. All PRT models result in the same trends of the self-heating errors; therefore, only the results of PRT model STS100A500 were presented. Figure 1 illustrates the self-heating errors of PRTs 100 Ω model STS100 A500 against the measured temperature for various sensing currents.

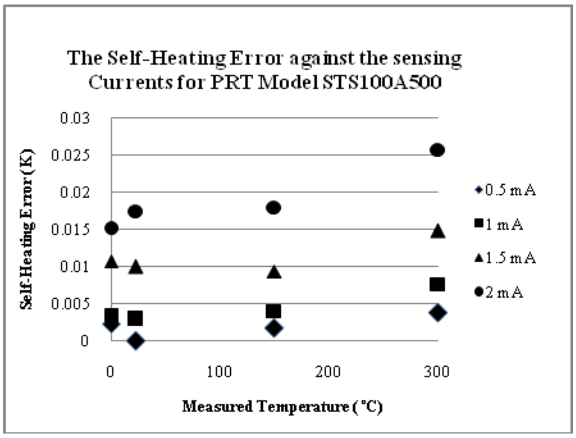


Figure 1. The self-heating error against the sensing current for PRT Model STS100A500 with various sensing currents.

As can be seen from Figure 1, at each sensing current the self-heating error at the measured temperature of 300 ˚C are the highest. In addition, the self-heating error increases with the sensing current. However, at low currents (0.5 mA and 1 mA) the measured temperature has less effect, comparing with the high currents (1.5 mA and 2 mA) as can be seen from the slopes of the graphs. When plotting the self-heating errors against the currents as shown in Figure 2, it could confirm that sensing current has strong effect on the self-heating errors as the slopes of all graphs are very deep.

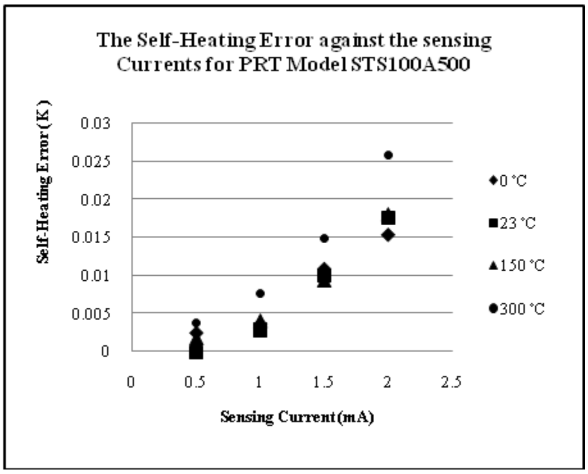
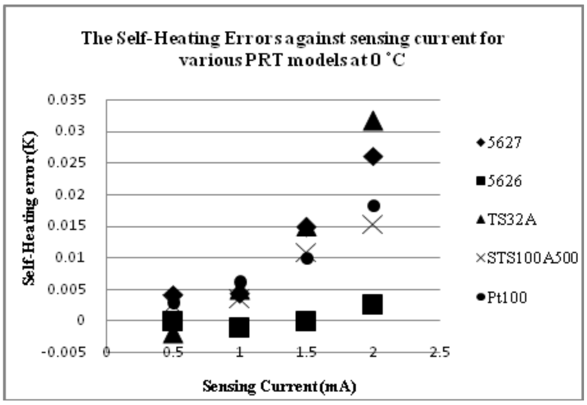
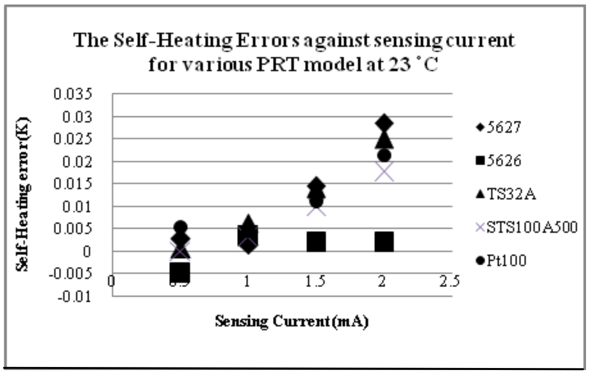


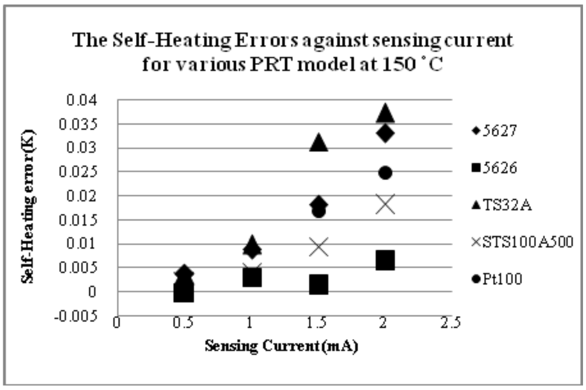
Figure 2. The self-heating error against the sensing current for PRT Model STS100A500 with various measured temperature.



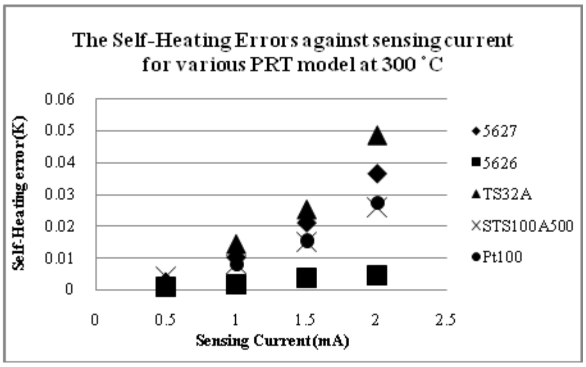
a)



b)



c)



d)

Figure 3(a-d). The self-heating errors against the sensing currents for various PRT models.

As can be seen from Figure 3(a-d), at the sensing current of 0.5 mA the results are very instable since there is no trend for the self-heating errors. This is corresponding to the result of the study of V. Batagelj that the low currents result in a high standard deviation of the measurement [7]. Additionally, apart from 0.5 mA, the self-heating error is the least at 1 mA current and the values of the self-heating errors are within 10 mK for every measured temperature. The highest self-heating errors occur at 2 mA current and 300 ˚C, the values are between 5 mK to 50 mK. The probe dimension has less effect on the self-heating errors for the low currents since there is no particular trend observed and the self-heating errors are not significantly different from each other. When the current is increased up to 2 mA, the effect can be seen more clearly. However, this is still not caused by the probe dimension because the self-heating errors are increased with neither increase nor decrease of both diameter and length.

The measured temperatures do not affect the self-heating errors as can be seen in figure 3(a-c) that the results are slightly different for the measured temperatures of 0 ˚C to 150 ˚C, the self-heating errors are between 5 mK to 30 mK. However, at 300 ˚C the self-heating errors are considerably larger than those in the other three temperatures, the values of the errors become 10 mK to 50 mK. Since the media in temperature sources are different, the thermal property of the media are considered and presented in Table 2.

Table 2: Thermal property of the medium at 25 ˚C in temperature source [8].

Medium	Thermal conductivity (W/(m·K))
Alcohol	0.17
Silicone Oil	0.1
Air	0.024

Alcohol has the highest thermal conductivity; thus, it should cause the least self-heating errors. However, the self-heating errors in oil bath are close to the self-heating error in the alcohol bath; this could be because the self-heating error is also dependent on the flow rate of the medium, which is not investigated in this research. The silicone oil at 150 ˚C might have a larger flow rate than the alcohol at 0˚C or at 150 ˚C the thermal properties of silicone oil might be altered. Not only air has the lowest thermal conductivity, but air is also not moving; as a result of this, the self-heating errors in the dry block at 300 ˚C are significantly higher than those at other measure temperatures.

4. CONCLUSION

It can be concluded that the sensing current has a strong effect on the self-heating errors of the PRTs 100 Ω; the larger the current used, the higher the self-heating error occurs. Although the lowest current used was 0.5 mA, but the current of 1 mA is more appropriate to be used because it gives the lowest self-heating errors with more stable results. The measured temperature and the probe dimension slightly affect the self-heating errors. The more important factor to be considered is the medium used, which has also shown the strong effect on the self-heating errors.

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