Calculation the instrument surface temperature for confirmation environmental qualification in service condition

Choi Geon Gyu*
Korea Hydro & Nuclear Power, Co., Ltd. #1 Hanul Nuclear power plant,
2040, Uljinbuk-ro, Uljin-gun, Gyeongsangbuk-do, Korea 36313
**Corresponding author: choigg0330@khnp.co.kr*

1. Introduction

According to IEEE-323 [1], the temperature of the equipment is the one of the main points to consider in the aging mechanism. The temperature of the equipment is affected by the ambient temperature and the operational condition [2]. To confirm the service condition for temperature, measuring the surface temperature of the equipment is the usual method. However, this method occasionally is impossible to utilize due to the situation of a nuclear power plant, such as the accessibility to the equipment. Therefore, the formula to calculate the surface temperature of the equipment is practical for estimating the service condition. This study suggests a method for calculating the surface temperature of the instrument.

2. Method for calculating the surface temperature

2.1 Assumption

The assumption of the following is required to calculate the surface temperature.

1) The instrument is in a steady state for the equilibrium of heat transfer.
2) The instrument is the only heat source.
3) Thermal energy transfers through conduction and convection of the plane surface.
4) Heat loss does not occur without heat transfer.

2.2 Derivation for the formula

Aassuming an instrument is under a voltage (V) and resistance (R) with the thickness (d),

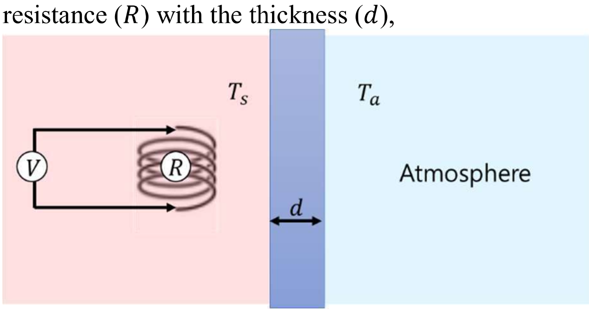

Fig. 1. The diagram of the instrument.

the thermal energy can be calculated by Joule heating law [3].

$$Q = V^2/R \tag{1}$$

This thermal energy transfers to the ambient air through conduction and convection [4].

$$Q_{convection} = hA(T_s - T_a) \tag{2}$$

$$Q_{conduction} = -k(T_a - T_s)/d = k(T_s - T_a)/d \tag{3}$$

where
h is the convective heat coefficient,
A is the surface area,
T_s is the temperature of the surface,
T_a is the temperature of the ambient,
k is the thermal conductivity,
and d is the thickness.

In the steady state, the thermal energy from the instrument is equilibrium with the heat transfer. Therefore,

$$Q = Q_{convection} + Q_{conduction} = hA(T_s - T_a) + kA(T_s - T_a)/d = (T_s - T_a) \times (hA + kA/d) \tag{4}$$

If the formula above is rearranged for T_s,

$$T_s = T_a + \frac{Q}{hA + k/d} = T_a + Q \cdot R_{th} = T_a + T_{heat\ rise} \tag{5}$$

R_{th} is the thermal resistance of the coil as the following.

$$R_{th} = \frac{1}{A(h + k/d)} \tag{6}$$

And $Q \cdot R_{th} = V^2/R \cdot R_{th}$ is the heat rise of the instrument. The surface temperature can be calculated utilizing the formula (5).

2.5 Application of the formula

Let RTD (Resistance Temperature Detector) covered with stainless steel is in the service condition with 0.5V and 160 ohms in the air. Thus, the convective heat coefficient and the thermal conductivity can be defined as the following [5, 6].

$h = 2.5[W/m^2 \cdot K]$
$k = 15[W/\cdot K]$

$T_{heat\ rise}$ varies with the surface area (A) and the thickness (d) in the graph below.

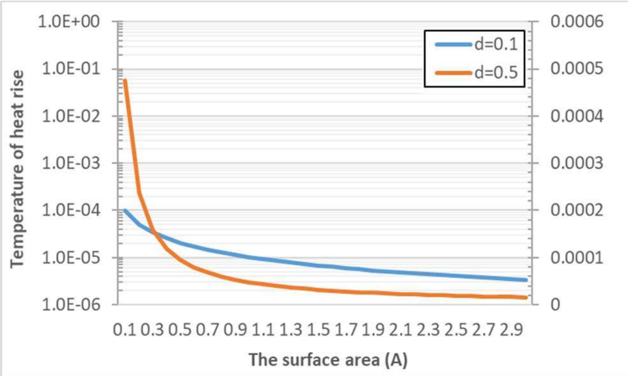

Fig. 2. The heat rise varying the thickness and surface area of the instrument.

When the thickness of the instrument is 0.1m (10cm) and the surface area is 100 cm^2 (0.01 m^2), $T_{heat\ rise}$ is 0.001℃. Therefore, the heat rise of RTD instrument has no significant effect on the surface temperature (T_s) because of the low voltage applied and the practical size of RTD instrument.

3. Conclusions

So far, the method to calculate the surface temperature is suggested. This method is advantageous for estimating the heat rise generated by the instrument. According to this method, RTD has no significant effect on the heat rise because the applied voltage is remarkably low. However, the higher voltage is applied, the higher the heat rise [6]. Therefore, the study to estimate the heat rise for the electrical motor and cable is necessary.

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