Experimental Verification on Precise Calorimetric Power Loss Measurement Using Two Chambers

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Abstract:- In this paper, the low cost Calorimetric Power Loss Measurement (CPLM) system for a high efficiency converter is proposed. The CPLM uses the heat quantity is generated by loss of the power converter. The proposed system is constructed at a low cost without the thermostatic chambers which cause a high cost of the CPLM system. The method for measurement of the power loss by the temperature rise with the loss of power converter is discussed. The experimental results confirmed the maximum error of power loss is 8% when the loss of power converter is 5W. This system can achieve that the measurement error rate is within 10%.

Keywords: Calorimetric determination, Power loss analysis, Thermostatic chamber

1. Introduction

Recently, the power converters become relatively high efficiency due to the advanced semiconductor devices and magnetic materials[1]. The power loss analysis of the power converter becomes difficult in terms of the measurement error because of the power losses decrease drastically. One of the loss measurement methods is to measure the input and output power using a power measurement instrument (EPM). However, this method has a risk including much error because the ratio of the power loss into output and input power is very small and full scale error of the measurement range cannot neglect to measurement results. On the other hand, the other loss measurements method using the heat quantity of the power converter is known as Calorimetric Power Loss Measurement (CPLM)[2]. This method can reduce the measurement error because this method can measure only power loss. Therefore, this method provides higher accuracy than the EPM. This system uses the thermostatic chambers for the precise measurement of heat quantity. However, thermostatic chambers are high cost structure.

In this paper, the low cost CPLM system using two chambers is proposed. The proposed system uses two simple chambers instead of thermostatic chambers. The validity of the proposed system is confirmed by the experiment using the prototype.

2. CPLM system using two chambers

Fig. 1 shows the control block diagram of the proposed system which is composed by two chambers and a heater. The chambers, which are made from insulator materials, are illustrated as the container A and container B in Fig. 1. A measured power converter is placed in the container A. The temperature in the container A rise due to the power losses generated from the power converter. The temperature in the container A saturates when the amount of heat dissipation from heater equals to the amount of heat dissipation from the container surface.

The temperature in the container B is controlled by a feedback control using the PI regulator. It should be noted that the air in the container B is heated by a heater, which is controlled by the buck converter. The temperature in the container A is set to the command of the PI regulator which controls the temperature in the container B. The sensitivity error of the temperature sensor was corrected in the control circuit. When the temperature in the container B reaches the command value that is the saturated temperature in the container A, the heat generation from the heater in the container B equals to the heat generated from the power converter in the container A. In this way, the power consumption of the heater equals to the power loss of the power converter.

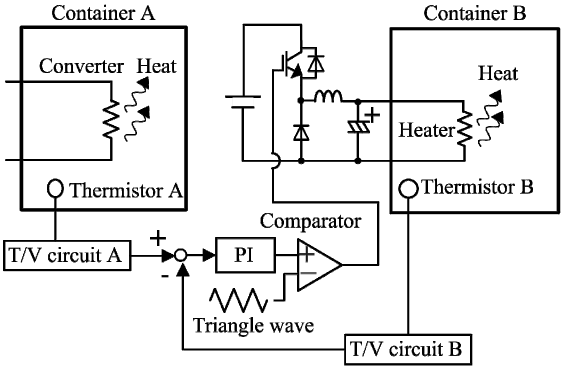

Fig. 1 System configuration of CPLM using two chambers.

The room temperature and heat discharge for the two chambers must be the same in order to obtain high accuracy measurement results in the proposed system. Therefore, in this paper, the developments of the measurement system will be discussed from the theoretical formula of the temperature rise in next chapter.

3. Theoretical discussion

The power converter is put and works in the container A. The temperature of the air in the container A rise, due to the heat quantity by the power loss of the power converter. The air in the container A is circulated by a fan in order to even out the temperature in the container A. When the inner volume of the container A is V (m^3), the density of the air is ρ (kg/m^3), the specific heat of air is c_p (J/gK), the temperature of the air in the container A is T_{in} (K) and the heat quantity (Q_{in}) can derive from

$$\rho c_p V \frac{dT_{in}}{dt} = Q_{in} - Q_R - Q_{cool} \tag{1}$$

where, Q_{in} is the heat quantity from the power converter to the air in the container A and Q_{cool} is the heat discharge from the container A. Then Q_R and Q_{cool} can be expressed as

$$\rho c_p V \frac{dT_{in}}{dt} = Q_{in} - \frac{T_R - T_{in}}{R_r} - \frac{T_{in} - T_{amb}}{R_{amb}} = Q_{in} - \frac{(Q_{in} \cdot R_r + T_{in}) - T_{amb}}{R} \quad (2)$$

where, T_R is the inner temperature of power converter, R_r is the thermal resistance from inside of the power converter to the measurement point of the room temperature, T_{amb} is the ambient temperature, R_{amb} is the thermal resistance of the container A, R is the total thermal resistances.

Eq. (2) is then transformed with Laplace transformation and presented as

$$\rho c_p V \left(s T_{in}(s) - T_o\right) = \frac{Q_{in}}{s}\left(1 - \frac{R_r}{R}\right) - \frac{T_{in}(s)}{R} - \frac{T_{amb}}{sR} \quad (3)$$

where, T_o is the initial temperature in the container A. The heat quantity of the power converter is assumed the step input. Eq (3) solves the T_{in}, and then it is applied with inverse Laplace transformation, which is shown in Eq. (4).

$$T_{in} = R\left\{Q_{in}\left(1 - \frac{R_r}{R}\right) + \frac{T_{amb}}{R}\right\} \cdot \left\{1 - \exp\left(-\frac{1}{\rho c_p V R}t\right)\right\} + T_o \exp\left(-\frac{1}{\rho c_p V R}t\right) \quad (4)$$

If the parameters are known except Q_{in}, Eq. (4) is differentiated and translated logarithmically to Eq. (5).

$$\ln\left(T'_{in}\right) = \ln\frac{R Q_{in} - R_r Q_{in} + T_{amb} - T_o}{\rho c_p V R} - \frac{1}{\rho c_p V R}t \quad (5)$$

As a result, the Q_{in} can derive by Eq. (5) before temperature becomes saturated.

4. Experiment results

4.1 Identification of the thermal resistance

For testing, a heater is used instead of the power converter. The power converter runs in the container A. The thermal resistances are identified from the experimental results of the temperature rise in the container A. Those experimental containers are made from foam cartons. The volume of the container is V = 3.17×10^{-2}m^3 (inner dimension of container; long 44.7cm, width 32.2cm, height 22.0cm). The error rate set up within 10%.

From Eq. (4), the permissible temperature deviation range (ΔT) is derived substituting with the permissible power consumption range, and the thermal resistances are obtained. Table 1 shows the thermal resistances and the permissible temperature deviation range. From Table 1, if the power consumption is small, the control of the temperature should be accurate. When the power consumption is 5W, the allowance of the temperature deviation is ±0.6 degrees Celsius.

4.2 Evaluation of the proposed system

The measurement accuracy is evaluated using the prototype. The power consumption of a heater in container B is evaluated toward the power loss of the power converter. The temperatures of air in the two containers are affected by the same ambient temperature because two containers are put in same place.

Fig. 2 shows the experimental result of the temperature control by using PI when the power consumption of power converter is 5W. From Fig. 2, it is conforms that the temperature in the container B is equaled to the temperature in the container A by using PI control.

Fig. 3 shows the measurement error rate of the power consumption of the power converter. From Fig. 3, it is conforms that the maximum error of power loss is 8% when the power consumption of power converter is 5W. The measurement error rate of the power consumption can be within 10% in the proposed system.

Table 1 Derivation result.

P_{loss} [W]	R [W/K]	R_r [W/K]	ΔT [℃]
5.0	34.0	32.8	±0.6
15.0	31.5	30.6	±1.4
25.0	30.3	29.5	±1.9

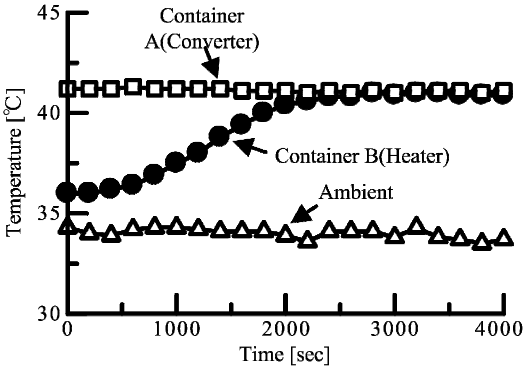

Fig. 2 PI control result.

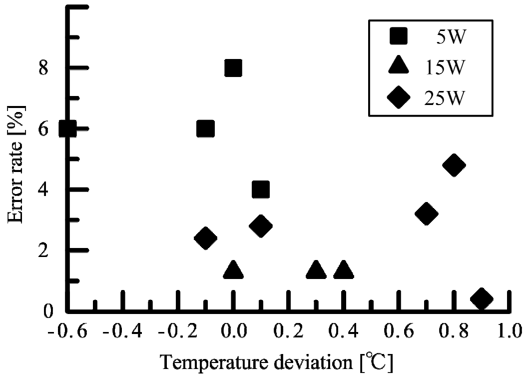

Fig. 3 Measurement error rate.

In theory, when the temperature deviation of the container A and container B is 0 degrees Celsius, the measurement error became 0% in this system. However, there are measurement errors in the experimental results. This reason is the difference of ambient temperature between the container A and the container B.

5. Conclusion

Abstract:- In this paper, the low cost CPLM system for a high efficiency converter is proposed. The CPLM uses the heat quantity is generated by loss of the power converter. The proposed system is constructed at a low cost without the thermostatic chambers which cause a high cost of the CPLM system. The method for measurement of the power loss by the temperature rise with the loss of power converter is discussed. The experimental results confirmed the maximum error of power loss is 8% when the loss of power converter is 5W. This system can achieve that the measurement error rate is within 10%.

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