An Alternative Calorimetric Approach for Power Loss Measurement of Ultra-efficient Power Electronics

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***Abstract*—This paper presents a calorimeter design for efficiency measurement of ultra-efficient power electronics. The proposed configuration utilizes a closed single-chamber, double-jacketed construction with a temperature-controlled heater. The main objective of the new design is to reduce measurement complexity without compromising accuracy. This is accomplished by measuring the change in electrical input power of the heating element while the controller maintains constant temperature, which serves as a measure of the losses of the power electronics.**

***Index Terms*—Power Electronics, Energy efficiency, Calorimetry, Power dissipation, Loss measurement.**

I. INTRODUCTION

Efficiencies in the field of power electronics can reach values up to 99 %. Consequently, measuring the efficiency of ultra-efficient power electronics becomes increasingly challenging. Conventional methods, such as direct Watt-meter measurements, face difficulties in achieving the necessary precision level of 0.1 %, since they indirectly measure the loss as the difference of output and input power.

Calorimetric approaches provide an effective way to measure losses in power electronics without the downsides of electrical methods. Since losses in electrical systems manifest as heat, their quantification is possible by measuring this heat. The primary goal of a calorimeter is to directly measure the power loss of a Device Under Test (DUT) within a thermally insulated enclosure.

Calorimeters come in various types and configurations, such as single or double (series) chamber calorimeters. While diverse in design, most calorimeters share the common objective of measuring the heat generated due to power losses, making the measurement dependent on the heat characteristics of the measurement chamber [1].

II. BACKGROUND

A calorimeter for power electronics is an apparatus used to measure and analyze the power losses in power electronic devices. One of the basic calorimetric methods involves using a container with a gas-coolant, typically air, to transfer dissipated heat. The power loss of the DUT is determined by measuring the air temperature difference (ΔT) between inflow and outflow, along with the mass flow rate ($\dot{m}$) and the heat capacity (C_p) of the coolant. The choice of a gas coolant, such as air, allows for fast response times but requires faster flow to compensate for the lower heat capacity compared to other fluids such as water.

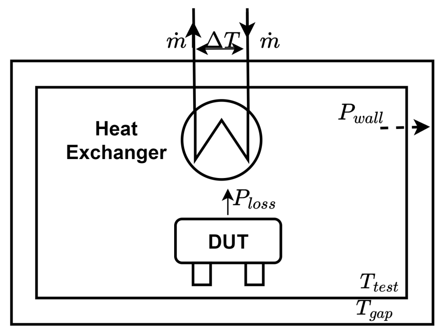

Fig. 1. Double Jacketed Closed-Type Single Chamber Calorimeter.

A. Closed-Type Double Jacketed Single Chamber Calorimeter

The closed-type double-jacketed single chamber calorimeter, shown in Fig. 1, is a popular configuration known for its accuracy in measuring power losses. In this design, an additional wall (double jacket) minimizes heat leakage, ensuring that almost all generated heat from the DUT is transferred into the coolant. This type of calorimeter is quite accurate but is often used for smaller-sized devices due to energy requirements and complexity [2].

B. Closed-type Series Chamber Double Jacketed

The closed-type series (double) chamber double-jacketed calorimeter, shown in Fig. 2, has two identical chambers, each surrounded by extra insulation. Where the first chamber encloses the DUT, the other chamber contains a reference heater. The continuous measurement of temperature gradients ($T_4 - T_3$ and $T_2 - T_1$) in both chambers is a key aspect, and the loss calculation does not require information of the coolant properties anymore. This design reduces the need for compensations due to environmental differences or internal changes.

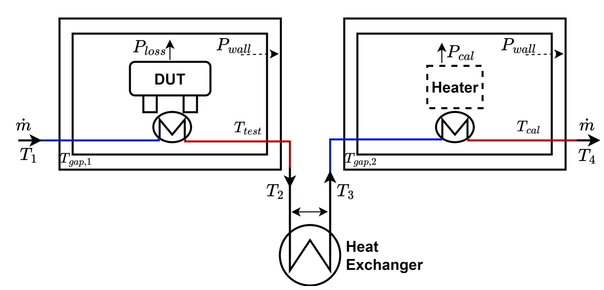

Fig. 2. Double Jacketed Closed-Type Series Chambers Calorimeter.

Both chambers receive the same coolant with adjustable flow rates, allowing to control the sensitivity of the calorimeter [3].

The calibration method, which uses a reference heater, increases accuracy by establishing a reference for comparison and identifying systematic inaccuracies. However, it increases response time and system complexity. In addition, scaling up serial chamber designs presents challenges, such as maintaining temperature uniformity, leading to a decrease in overall robustness.

III. Proposed Calorimeter Design

By combining design principles [4], a closed-type single-chamber, double-jacketed calorimeter controlled by a temperature controller is proposed. The ultimate goal of the proposed design is to measure losses by direct comparison with a reference heater, giving the design similar properties to the series-chamber calorimeter. The power loss in the DUT is determined by the difference in heater power input, while maintaining a constant temperature in the calorimeter, before and after activating the DUT, expressed as $P_{DUT} = \Delta P_{\text{heater}}$.

As shown in Fig. 3, the DUT sits on one of two base plates. A heater is placed next to the DUT inside the inner walls. A temperature control unit, monitoring the heater's temperature, regulates its power input. The concept involves maintaining the temperature of the inner walls a few degrees above ambient. The heater adjusts its power to sustain the desired temperature and reach a steady state, and as the DUT dissipates heat, the power input decreases proportionally, becoming a measure for the DUT's heat dissipation.

Wall materials

Heat tends to escape through various pathways such as walls, mounting bedplates, shaft linkages, and connecting ports to the surrounding environment. These losses can be effectively mitigated by implementing external temperature compensations, such as active temperature control, along with appropriate insulation arrangements to maintain an isothermal condition across the boundaries. The outer walls are made of a thin layer of highly heat-conducting metal (e.g., aluminum) and a layer of insulating material (e.g., polystyrene). Utilizing metals on the surface of structures serves the dual purpose of promoting heat conduction and minimizing non-uniformities in the temperature profile across panel walls.

The inner walls are also made of a thin layer of highly heat-conducting metal. To increase accuracy and stability, heaters are placed on the outer walls of the chamber. The reference heater is placed in the inner chamber as close as possible to the DUT.

The dimensions of the chambers must align with the characteristics of the devices undergoing measurement. Specifically, for an average 5 kW power converter, the chamber dimensions are set at $0.3\,\text{m} \times 0.3\,\text{m} \times 0.3\,\text{m}$ (length $\times$ width $\times$ height). A gap of 5 cm is maintained between the outer and inner walls.

Given the high efficiency of the targeted converter class, ranging from 98 % to 99 %, the expected power loss is between 50 W and 100 W for a 5 kW converter. Therefore, the test setup should ideally be able to measure a power loss of up to 150 W.

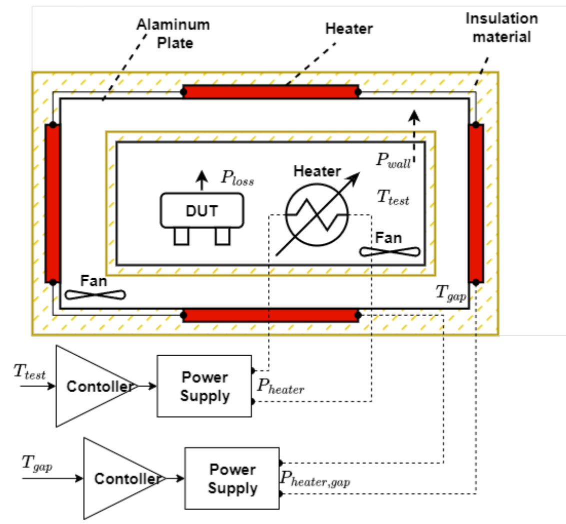

Fig. 3. Schematic design of the proposed calorimeter.

As an initial design check, the temperature of the outer walls is controlled at 28 °C with a deviation of about 10 mK.

IV. Conclusion

A new calorimeter design is presented for measurement of the losses in ultra-efficient power electronics. The proposed design employs a closed, single-chamber, double-jacketed structure along with a temperature-controlled heater. This approach eliminates the necessity to measure all thermal parameters, concentrating instead on accurately determining the input power of the heater.

Present work focuses on implementation of this calorimeter design and validation of its accuracy.

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