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Model development for thermal simulation of electromechanical integrated electric water pump

Yasutaka Aoyama [1)]

1) Aisin Corporation
2-1 Asahi-machi, Kariya, Aichi, 448-8650, Japan

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An Electric Water Pump (EWP) is an automotive component that electrifies the water pump traditionally driven mechanically by engine rotation. In a mechanical system, crankshaft rotation is transmitted to the pump through a belt, and coolant flow depends on engine speed. In contrast, an EWP employs a dedicated electric motor, enabling operation independent of engine speed and allowing coolant flow to be controlled according to driving conditions (e.g., immediately after start-up, low-speed operation, and high-speed cruising). This flexibility reduces energy loss due to overcooling and contributes to improved fuel economy; it also requires an Electronic Control Unit (ECU) to control the motor.To enhance packaging, recent automotive products often adopt a mechatronically integrated structure in which mechanical and electronic units are combined. The EWP is one example, integrating an ECU section, a motor section, and a pump section within a compact assembly. Such integration introduces complex thermal interactions among the sections, and boundary conditions such as ambient temperature and coolant temperature vary with vehicle specifications and usage environments. In some cases, the direction of heat flow may even reverse, making early-stage prediction of ECU component temperatures difficult. Moreover, ECU design trends toward simultaneous miniaturization, cost reduction, and higher functionality increase thermal severity: mounting density rises while available heat-dissipating area decreases; metallic housings are replaced with resin materials with lower thermal conductivity; and component heat generation increases with higher output and functionality.

Against this background, we develop a thermal simulation model for a mechatronically integrated EWP through staged modeling-from individual electronic components, to the printed circuit board, to an ECU-level model, and finally to a full mechatronic model including the mechanical structure. This paper focuses on modeling an integrated circuit (IC) within the ECU, emphasizing the need to estimate internal temperatures, particularly semiconductor junction temperature, which governs reliability, lifetime, and operating limits. Conventional detailed models require internal geometry and material properties that are often unavailable to system manufacturers, and reverse engineering (e.g., X-ray inspection and dimensional reconstruction) is time-consuming and uncertain.

We therefore adopt a measurement-based approach using T3STER to characterize transient thermal behavior and convert it into a multi-stage RC thermal network that can be embedded into a three-dimensional simulation model. T3STER measurements consist of heating and cooling phases. Conventionally, the sensing current during the cooling phase is set very small to avoid measurement-induced self-heating; however, unexpected behavior can occur due to the influence of the IC's internal circuitry. As shown in Fig.1 left, a temporary temperature increase was observed during cooling, although a monotonic decrease is expected, suggesting that internal circuitry affects the PN-junction voltage used for sensing. To address this issue, we investigate increasing the sensing current during the cooling phase. The result Fig.1 right eliminates the abnormal temperature rise and restores the expected monotonic cooling behavior, enabling accurate extraction of IC thermal characteristics and reliable thermal model construction.

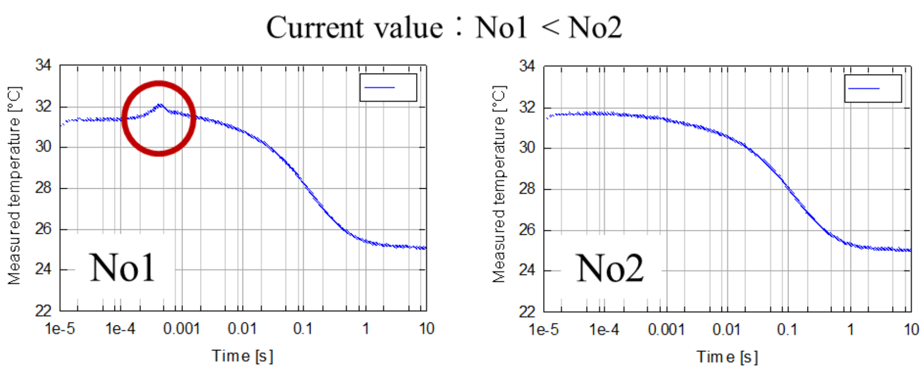

Fig.1 Measurement Results of IC Thermal Characteristics

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