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Development of the double-sided cooler for the inverter

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The demand for electrified vehicles continues to increase, accompanied by higher power density and compactness requirements for inverters. As a result, the heat generation density of power semiconductor devices has increased, making thermal management a critical issue. Double-sided coolers have been widely adopted for inverter applications because they enable heat removal from both sides of the semiconductor devices and offer higher cooling performance than conventional single-sided cooling structures. However, further improvement in cooling performance is required, while limiting the increase in pressure loss in the coolant flow.

In this study, an inner fin for a double-sided cooler was investigated with the objective of improving cooling efficiency while maintaining reasonable pressure loss. Conventional fin designs have mainly relied on fin miniaturization and increased heat transfer area to enhance cooling performance, which often results in a significant increase in pressure loss. This trade-off has made it difficult to achieve further improvements in overall cooling efficiency using conventional design approaches.

To address this issue, topology optimization was applied to an existing offset wave fin (Wave pitch 2.8). Cooling efficiency, defined as the ratio of cooling performance to pressure loss, was used as the objective function. Repeated optimization calculations were conducted, allowing changes in fin topology such as the formation of holes and protrusions. Although the optimized shape achieved higher cooling performance compared with the initial design, it exhibited a complex geometry that was not suitable for mass production. Therefore, the shape evolution process during topology optimization was analyzed in order to extract the fundamental mechanisms contributing to performance improvement.

From this analysis, two primary mechanisms were identified. One mechanism is the formation of wall holes that generate secondary flow paths, which reduce pressure loss by alleviating direct collision of the main flow with the fin walls. The other mechanism is the enhancement of heat transfer through a leading-edge effect caused by wall protrusions located in high-velocity regions of the main flow. These features were observed consistently during the optimization process and were considered to play an important role in improving cooling efficiency.

Based on the extracted mechanisms, key design parameters were defined to translate the optimized concept into a manufacturable fin geometry suitable for press forming. These parameters included the width and position of wall holes to control secondary flow formation, as well as wall angles to guide the flow smoothly toward the protrusions while suppressing flow separation. The interactions among these parameters were evaluated systematically, and a design target shape was derived while considering pressure loss (Fig.1).

The resulting inner fin design reproduced the characteristic flow features of the topology-optimized shape while maintaining constant plate thickness and manufacturability. Experimental evaluation was conducted using a single-tube test setup. The developed fin showed approximately 1.4 times higher cooling performance and approximately 1.5 times higher pressure loss compared with the offset wave fin introduced in 2021. In addition, when compared under equivalent cooling performance conditions, the developed fin demonstrated a significant reduction in pressure loss relative to a conventionally miniaturized offset wave fin (Wave pitch 1.8).

In conclusion, this study demonstrates a design approach in which topology optimization is used to identify essential heat transfer and flow control mechanisms, and these mechanisms are subsequently reflected in a practical fin design suitable for mass production. The proposed methodology was found to be effective for improving the cooling efficiency of double-sided inverter coolers and may be applicable to future inverter cooling systems with higher power density.

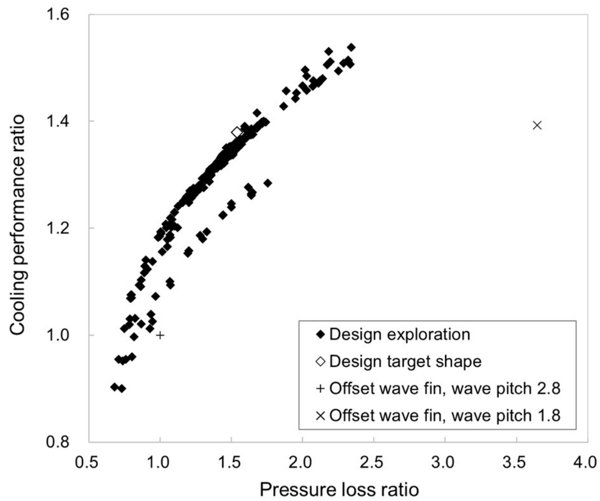

Fig. 1 Search for optimal design points

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