

Development of a High-Power Density Motor (5th Report)

- Causes and Reduction of Nonuniform Coil-End Temperature Rise in Direct Oil Cooling -

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In this study, we experimentally investigated the cooling performance of the direct oil cooling structure developed for a high-power-density traction motor. The developed motor has a maximum output of 348 kW, a maximum torque of 414 Nm, and a maximum rotational speed of 20,000 rpm. The cooling structure consists of three oil paths: a shower path for the outer side of the coil end, a stator-core path, and a rotor path that cools the rotor core and magnets before supplying oil to the inner side of the coil end (Fig.1). Temperature measurements revealed nonuniform coil-end temperature rise, particularly at the 6 and 3 o'clock positions.

To clarify the mechanism causing this temperature nonuniformity, the cooling effect of each oil path was evaluated separately and the internal oil-flow behavior was visualized (Fig.2). The shower oil provided strong cooling near the upper coil-end region, whereas the rotor oil complemented regions that were difficult for the shower oil to reach. Visualization showed different mechanisms at the two high-temperature locations. At the 6 o'clock position, oil flowing downward along the coil end was discharged mainly around the 5 and 7 o'clock positions before reaching the bottom region. At the 3 o'clock position, the tangential velocity component induced by rotor rotation opposed the downward oil flow and promoted oil dispersion away from the outer coil-end surface. These results indicate that insufficient oil accessibility, rather than total oil flow rate alone, is a key factor governing local temperature rise.

Based on these findings, the stator-side oil-flow distribution was modified without increasing the total oil flow rate. The proportion of stator-side oil supplied through the stator-core path was increased from 29% to 71%, improving oil delivery to the lower coil-end region. This redistribution reduced the temperature rise at the 6 o'clock position by 30%. More importantly, the maximum coil-end temperature rise was reduced by 25%, while the circumferential temperature-rise variation was reduced by 54% (Fig.3). Thus, appropriate oil-flow distribution can improve both local cooling performance and temperature uniformity without increasing the total cooling-oil requirement.

To further improve cooling performance, the effect of coil-end geometry was investigated using three-dimensional thermal-fluid analysis. Increasing the gap between winding conductors improved the penetration of rotor-supplied oil into the coil end and expanded the effective wetted area, resulting in greater heat transfer even at locations far from the rotor. However, increasing the conductor gap may also increase coil-end length and adversely affect motor packaging and losses. Therefore, future development requires integrated optimization of oil-flow distribution, rotor-side cooling, and coil-end geometry. These results demonstrate that controlling oil accessibility to the heat-generating regions is a key design principle for improving the cooling performance of high-power-density direct oil-cooled motors.

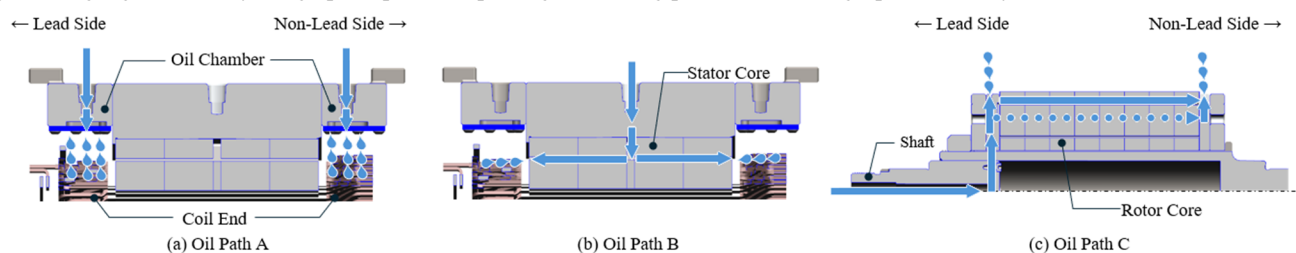


Fig.1 Direct Oil Cooling Structure

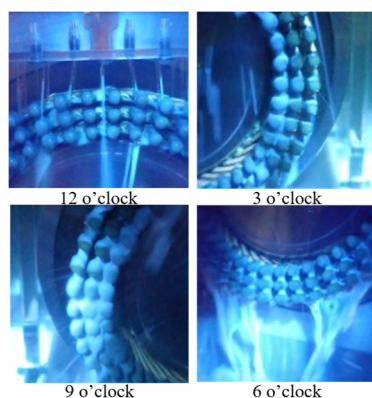


Fig.2 Oil Flow Behavior at the Coil End
(3,000 rpm, Shower 2.5 L/min per side, Stator Core 2 L/min, Rotor 4 L/min, Oil temperature 85°C)

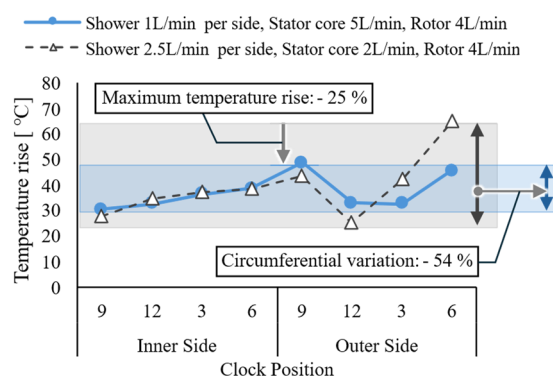


Fig.3 Effect of Stator-Side Oil-Flow Redistribution on Coil-End Temperature Rise
(250 Nm, 3,000 rpm, Oil temperature 85°C)