

Development of a High-Power Density Motor (Fourth Report)

-Integrated Electromagnetic and Mechanical Design for 10 kW/kg-Class Power Density within a Feasible High-Speed Design Window-

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This study presents the development of a high-power-density traction motor targeting more than 10 kW/kg. In the first to third reports, we developed a magnetic circuit and direct oil-cooling structure and experimentally demonstrated a power density of 8.8 kW/kg at 16,000 rpm. To further increase power density without relying primarily on advanced materials or a major system-voltage change, high-speed operation was selected as the main development approach.

However, simply increasing rotational speed is not sufficient. Higher speed increases rotor stress and requires structural measures that can increase leakage flux and reduce electromagnetic performance. Therefore, the key issue is to establish a feasible design window in which the benefits of higher speed coexist with electromagnetic, mechanical, and thermal constraints (Fig. 1).

To expand this window, the design concept itself was reconsidered rather than simply optimizing existing parameters. The large inner air gap of the first-report motor was replaced by multiple small flux barriers (Fig. 2). This reduced stress concentration and the average bridge thickness from 0.94 mm to 0.83 mm while satisfying the mechanical-strength requirement at 20,000 rpm. The magnetic circuit was redesigned for deep flux-weakening, while direct oil-cooling paths were integrated into stator and rotor magnetic circuits.

The practical high-speed design point was determined by evaluating the bridge thickness and maximum torque from 16,000 to 22,000 rpm (Fig. 3). As speed increased, the required bridge thickness increased and maximum torque decreased due to increased leakage flux. From 20,000 rpm, the torque deviated from the lower-speed trend, reaching a difference of approximately 12 Nm at 22,000 rpm. Based on this trade-off between the benefit of higher speed and its electromagnetic penalty, 20,000 rpm was selected as the practical design point.

Prototype testing demonstrated 414 Nm and 348 kW. Increasing the maximum speed from 16,000 to 20,000 rpm enabled a 16% mass reduction while maintaining comparable output, resulting in 10.3 kW/kg, approximately 17% higher than the first-report motor (Fig. 4). The measured results agreed with CAE, and an over-speed test confirmed the mechanical feasibility of the 20,000 rpm design point.

These results demonstrate that achieving 10 kW/kg-class power density requires not speed increase alone, but reconsideration of the structural concept and integrated electromagnetic, mechanical, and thermal design within a feasible high-speed design window.

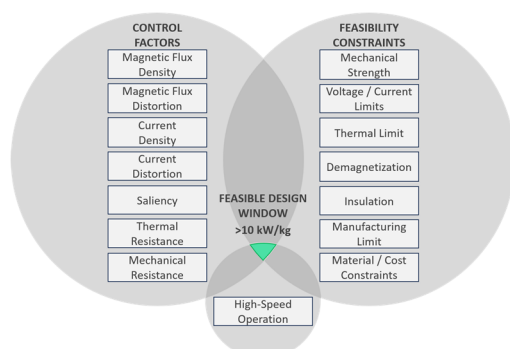


Fig.1 Concept of Feasible Design Window

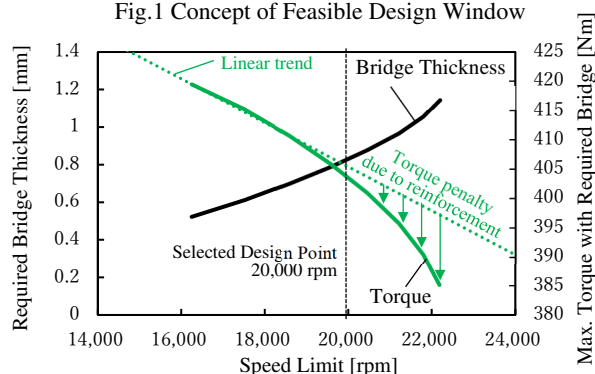


Fig.3 Effect of Rotor Speed on Bridge Thickness and Torque

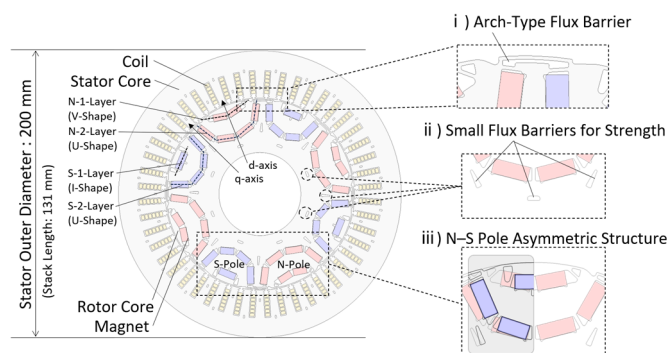


Fig.2 Magnetic Circuit Structure of New Type

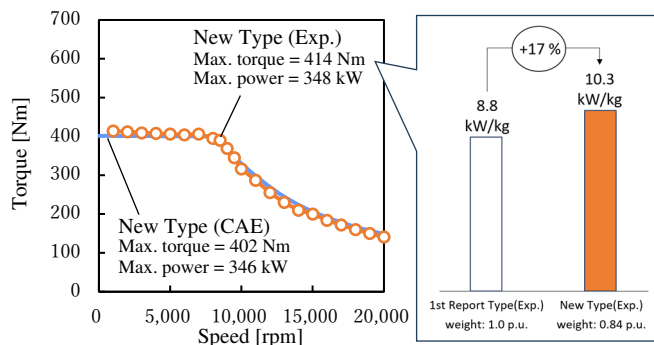


Fig.4 Measured Performance of New Type