

Development of a Model-Based 2-Stage Motor System Inverter Durability Test Mode Reflecting Customer Usage

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A two-stage motor system improves EV power performance by operating two inverters according to vehicle driving conditions. Because the operating regions of Inverter 1, Inverter 2, and split switches vary significantly depending on customer driving patterns, durability targets should be established using representative vehicle usage conditions. This study proposes a model-based process for developing accelerated durability test modes for a two-stage motor system inverter that reflect real-world customer operation.

The proposed methodology consists of two stages. First, customer-representative simulation scenarios were generated using a multi-physical electric vehicle model and rotating Rainflow matrix optimization. The vehicle model included chassis, battery, motor, reduction gear, inverter loss, and control system models to evaluate both mechanical and thermal load characteristics. To represent a broad range of customer operating conditions, 440 simulation modes were established by combining representative driving cycles, vehicle mass conditions, and road gradients. An optimized simulation scenario equivalent to approximately 300,000 km of customer vehicle operation was then derived from real-world customer usage data.

Fig.1 shows the results of the rotating Rainflow matrix optimization. The generated simulation scenario successfully reproduced the shaft matrix and tooth matrix distributions observed in customer operation. Good agreement was achieved not only for torque ranges and cycle counts but also for accumulated damage distributions across the entire operating range, indicating that the optimized simulation scenario effectively captures the usage characteristics contained in large-scale customer databases.

To verify the applicability of the generated scenario for inverter durability development, electrified powertrain signals obtained from the simulation scenario were applied to a two-stage motor system inverter model. Comparison with customer usage data showed that the thermal damage levels of individual inverters and switching devices were reproduced with an error of less than 5%, demonstrating that the proposed approach can accurately represent customer operating conditions from both mechanical and thermal durability perspectives.

In the second stage, the customer-representative simulation scenario was applied to a newly developed vehicle equipped with a two-stage motor system inverter. Thermal damage levels calculated from vehicle simulation were used as target values for accelerated durability test development. A multi-objective optimization procedure was employed to determine the optimal combination of component-level durability patterns while satisfying allowable test-duration constraints. The optimized durability test mode successfully reproduced the target thermal damage levels of Inverter 1, Inverter 2, and split switches within the acceptance criteria and was applied to engineering validation activities.

The proposed process enables customer usage-based durability target setting and efficient development of accelerated durability test modes for two-stage motor system inverters. The methodology can improve durability assessment efficiency while maintaining the representativeness of real-world vehicle operation and can be extended to future electrified powertrain systems.

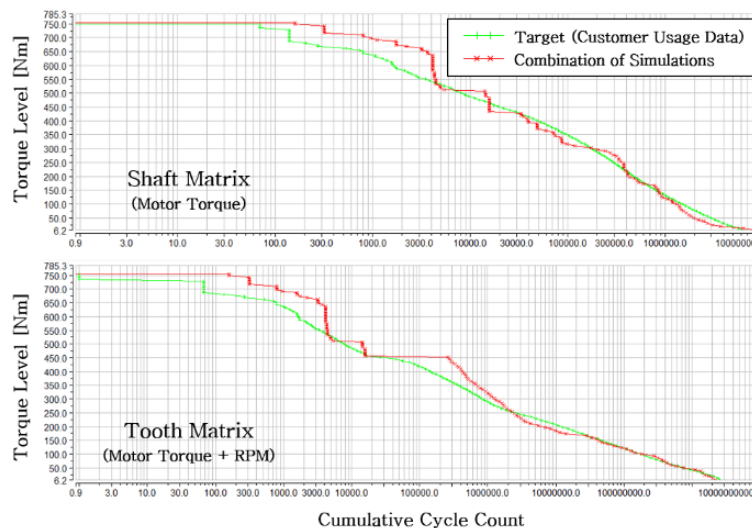


Fig.1 Results of the rotating Rainflow matrix optimization.