講演番号	275

The Evolution of Power Unit Development Process through MBD

- (Twelfth Report) Drivability Performance Verification Using Power Unit Transient Bench -

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KEY WORDS: EV and HV systems, energy control system, system technology, standardization [A3]

The rapid advancement of vehicle electrification and intelligence has significantly increased the complexity of automotive power unit (PU) development, creating strong demand for higher development efficiency and improved performance quality. Drivability (DRB) performance, which represents a driver's subjective perception of vehicle response, has traditionally been evaluated through expert sensory assessment using prototype vehicles. This approach requires substantial development resources, limits testable conditions, and suffers from poor reproducibility due to evaluation dependency. To address these issues, this study proposes a methodology to substitute vehicle-based DRB performance verification with a Power Unit Transient Bench (PTB), enabling quantitative, reproducible, and comprehensive verification under realistic usage conditions.

Drivability performance is difficult to quantify because it is commonly expressed using sensory descriptors such as responsiveness, acceleration feel, and controllability. Evaluation results have relied heavily on expert tacit knowledge, making consistency across evaluators and development phases difficult to maintain. When physical quantities are considered, differences in measurement and calculation methods across test systems degrade reproducibility. Furthermore, reproducing transient driving conditions on a bench system is challenging for a hybrid PU because operating modes depend on driver input, vehicle state, battery state of charge (SOC), and thermal conditions. These challenges have prevented effective substitution of vehicle-based DRB evaluation with bench testing.

To overcome these limitations, six DRB metrics were defined: sense of unity, initial response, response to expected acceleration feel, sustained acceleration feel, low-to-mid speed margin feel, and speed controllability. For each metric, a requirement analysis based on working hypotheses was conducted, clarifying relationships between driver requirements, vehicle system requirements, required physical characteristics, and physical quantities. Correlation analyses were performed between expert evaluation scores and candidate physical metrics derived from the hypotheses. Sufficient correlations were confirmed for all six metrics, and the coefficient of determination reached 0.81 for the sense of unity metric as a representative example (Fig.1). These results demonstrate that sensory drivability attributes can be quantitatively evaluated using physically measurable indicators.

Based on these results, several technologies were introduced to improve evaluation reproducibility on the PTB. First, vehicle acceleration measurement was standardized by defining an equivalent calculation method consistent with onboard acceleration sensors and implementing it within the PTB simulation model. Validation confirmed close agreement between vehicle and PTB acceleration responses. Second, a driver model equivalent to that used in chassis dynamometer testing was constructed by identifying PID control gains and response delays. This enabled accurate reproduction of pedal operation and vehicle acceleration behavior on the PTB, demonstrating that DRB verification previously conducted using actual vehicles can be substituted by the PTB. Third, the battery model was enhanced to allow flexible SOC control and rapid condition reproduction through a retriggered SOC function, ensuring efficient reproduction of desired PU operating states for short evaluation scenarios.

The equivalence between vehicle-based and PTB-based evaluation was verified by comparing all six-drivability metrics, which showed complete agreement between the two environments (Fig.2). The proposed methodology was then applied to comprehensive verification involving approximately 3,000 driving conditions combining vehicle speed, SOC, PU operating modes, acceleration patterns, gradients, and drive modes. Automated test execution and post-processing enabled efficient identification of abnormal PU behavior without extensive vehicle testing. As a result, the evaluation period was reduced by approximately 60% compared with conventional vehicle-based verification.

These results demonstrate that the proposed PTB-based drivability verification framework successfully transforms subjective sensory evaluation into a quantitative, reproducible, and efficient development process, providing a practical foundation for advanced PU and future vehicle development activities.

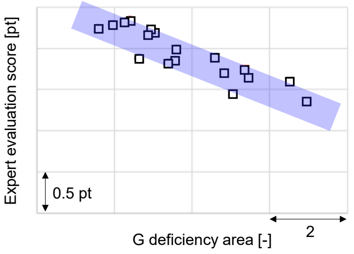

Fig.1 Validation result of correlation between physical quantity and EXP score (sense of unity)

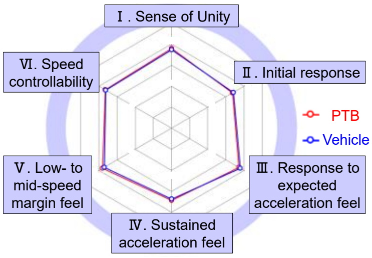

Fig.2 Validation result of PTB reproducibility for DRB metrics

2026 JSAE Annual Congress (Spring) - Summarized Paper
Issued on May 22, 2026