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Study on Performance Analysis of Mild Hybrid Powertrain Applicating Multi-Domain Modeling

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One of the roles of MBD is to look over the entire system consisting of multiple physical domains and to perform co-design between components in the early stages of development. In particular, the above role of MBD is extremely important for the development of electrified powertrain systems, since it deals with multiple domains such as mechanical, electrical, and control. Among electrified powertrain systems, mild hybrid powertrain systems are highly dependent on the engine and have been reported to be used in combination with an electric supercharger. In this case, modeling for multi-domain applications is required since the energy flow crosses electrical-mechanical-thermal-fluid-mechanical domains.

In this study, a modeling method for mild hybrid powertrains by applying the Modelica language, a multi-domain modeling language, were developed. Furthermore, a performance analysis method by simulation using the model were proposed.

Based on the engine cycle simulation model developed in our previous paper, the engine system equipped with electric supercharger were developed by adding a compressor model, a brushless DC (BLDC) motor model, and a control model. The compressor model consists of a rotational mechanical domain and a thermal-fluid domain. It is operated by connecting the shaft connector to the connector of the rotating mechanical domain of the BLDC motor model. The BLDC motor model consists of an electrical domain and a rotational mechanical domain. The rotational speed and current of the motor are calculated by controlling the duty cycle of the voltage applied to the stator.

The ISG (Integrated starter generator) model was developed by applying the BLDC motor model. Unlike BLDC motors that use permanent magnets in the rotor, the ISG controls the magnetic force by the current in the rotor winding. Therefore, the ISG model controls the current by controlling the duty cycle of the voltage applied to the rotor winding, and the torque constant (back electromotive force constant) varies with duty cycle.

In the ISG control model, the duty cycle of the voltage applied to the rotor and stator is determined by establishing the same physical equations as in the equivalent circuit model, and calculating the duty cycle of the voltage applied to the rotor and stator backward from the required motor torque.

The mild hybrid electric vehicle equipped with an electric supercharging engine, shown in Figure 1, was modeled by incorporating the mild hybrid powertrain system with component models developed above, the newly developed CVT model, battery model, and hybrid system control model into the vehicle simulation model. In the model, the vehicle actively regenerates deceleration within the range of battery SOC (State of charge) (40-80%).

Simulations were conducted for a K-car equipped with a 12 V mild hybrid system under WLTC (hot) to analyze the energy flow between the components. Figure 2 shows the total WLTC fuel and electric energy consumption and the work done at the connection points of each component. The negative work at the wheel hubs is the source of energy for regenerative braking. In this vehicle, however, it is approximately 30% of the positive drive work, and only approximately 20% of it is regenerated as electrical energy. It was shown that only a small amount of energy was used for supercharging by the electric supercharger and assisting by the ISG, and this modeling method enables detailed energy flow analysis.

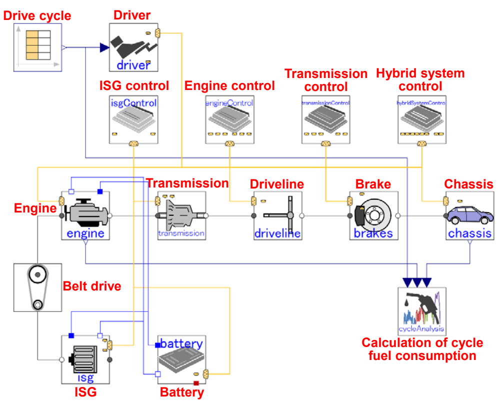

Fig.1 Mild hybrid electric vehicle model

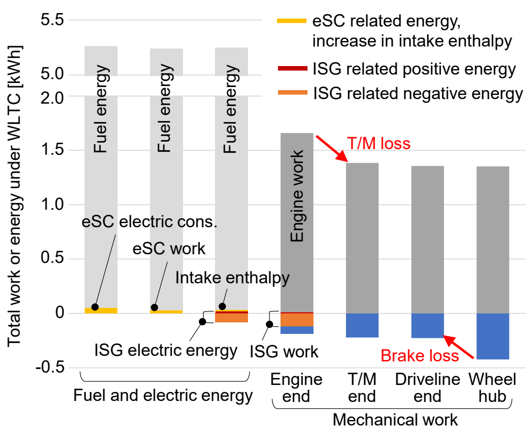

Fig.2 Total work or energy in WLTC at each point of components