High-precision evaluation system of EV motors in low-speed conditions for improving motor control

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ABSTRACT: In recent years, vehicles have become increasingly electrified and individual wheel control has become possible. This has led to an increase in demand for vehicle and powertrain testing using a hub dynamometer as a vehicle test bench. Although a hub dynamometer measures shaft torque and rotational speed and can reproduce various operating conditions, the number of encoder pulses installed for speed measurement, which covers from low to high rotational speed range, is limited. This study achieves improved operational accuracy of a hub dynamometer by obtaining angle and speed information at very low rotational speeds from an encoder with a limited number of teeth by adding detector heads for rotational speed measurement and signal processing, without installing a new high-resolution encoder. As a result, it is now possible to evaluate the start and stop behavior of electric vehicles that can freely generate large torque from a standstill, to evaluate force-regenerative switching at low rotational speeds, to evaluate mechanical brake intervention during deceleration, and to evaluate start and stop behavior on hills with high precision and reproducibility.

KEY WORDS: electric vehicle, power electronics, motor, powertrain, evaluation system

1. INTRODUCTION

Test bench that directly connects a wheel hub to a dynamometer (hereafter referred to as "hub dynamometer") has come to be used as a vehicle evaluation and powertrain evaluation equipment (Fig.1). The hub dynamometer can reproduce transient behaviors that cannot be realized by the chassis dynamometer without including the tire. It can also be used to evaluate vehicle control including regenerative braking for electric vehicles and automatic driving functions through independent control of all four wheels. In addition, technological improvements in induction motors and synchronous motors using permanent magnets have led to the widespread use of test equipment capable of operating from standstill to forward and reverse rotation, and even up to high speeds. Initially, these test benches were designed to test vehicles powered mainly by fossil fuels, and because there was little need for testing and evaluation in the stop to low speed range, encoders with a limited number of teeth that can measure up to high speeds have been used as detectors to control the test bench.

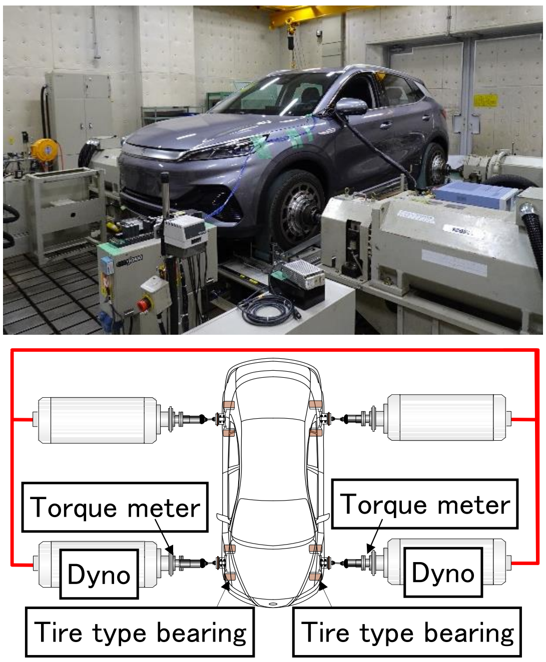

Fig.1 Hub dynamometer

This has resulted in inadequate evaluation of electric vehicles in the low rotational speed range. In this study, the accuracy of operation in the low rotation speed range was improved by adding detector heads and signal processing.

2. LOW ROTATIONAL SPEED MEASUREMENT

Fig. 1 shows the configuration of the hub dynamometer. A flange-type shaft torque detector, a ring gear for rotation speed detection, and a magneto-electric rotation detector of the pulse output type are installed at the boundary between the dynamometer and the work piece.

A schematic diagram of the measurement principle is shown in Fig. 2. To determine the direction of rotation and measure the angle, a 90[°] phase difference signal is generated and used as the phase A analog signal and phase B analog signal. The rotation angle is calculated from these two signals using the inverse tangent function. Since analog signals are used, there is a possibility that the signal level will fluctuate due to the eccentricity of the rotation axis. Therefore, the detectors are placed 180[°] opposite each other, and their outputs are added together to minimize the signal level variation due to eccentricity. For this reason, a total of four magnetic detector heads are installed.

To verify the detection of low-speed rotation, a laser Doppler surface velocity meter that can measure from zero speed was used for comparative verification. The results of increasing the rotational speed of the dynamometer alone are shown in Figure 2. Compared to the conventional encoder, the measured value from the low rotation speed detection is closer to the value measured by the laser Doppler surface velocity meter.

The analog signal of the low rotational speed detector and the existing pulse signal as the control feedback value were used according to the controller's calculation period. In the low rotational speed range of 50 [r/min] or less, analog signals of phase A and phase B are used, and in the high rotational speed range, rotational speed is measured by pulses (Table 1).

3. RESULTS OF LOW ROTATIONAL SPEED MEASUREMENT ON DYNAMOMETER

In the past, the responsiveness of pulse measurement decreased in the low rotational range, and the responsiveness of control had to be lowered accordingly. This has reduced the actual road reproducibility in the low rotational speed range. By using a low rotational speed detector, the same control response can be achieved in the low rotational speed range as in the high rotational speed range. This improves control accuracy in the stop to low rotational speed range and improves the reproducibility of various evaluation tests. Fig. 3 shows a comparison of turning from zero rotational speed. It can be seen that with the control gain increased, the rotation speed follows the reference value well.

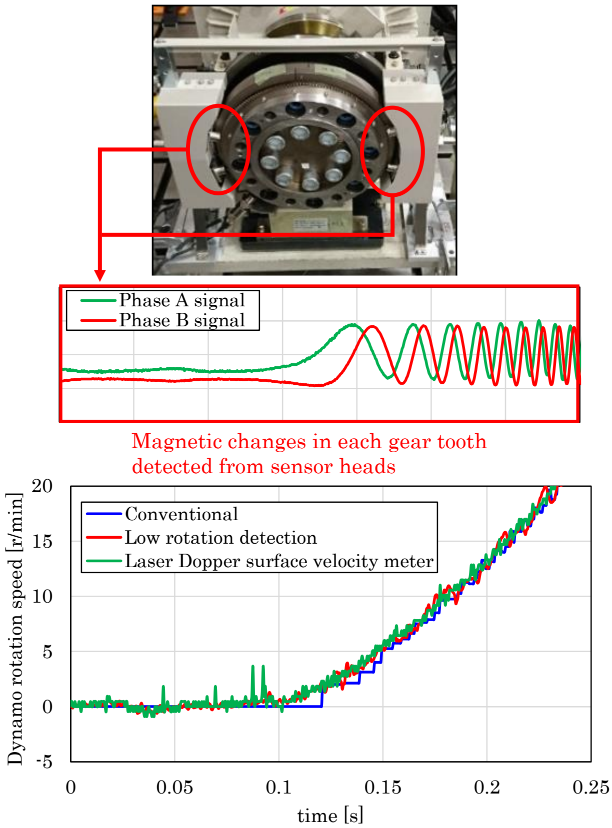

Fig. 2 Verification of low rotational speed detector

Table 1 Measurement method for rotational speed range

Rotational speed range	Signal used	Rotation speed measurement method
Less than 50[r/min]	Phase A phase B analog angle signal	Rotational speed by time derivative of measured angular change
50[r/min] or more	Pulse signal	Rotation speed by periodic measurement

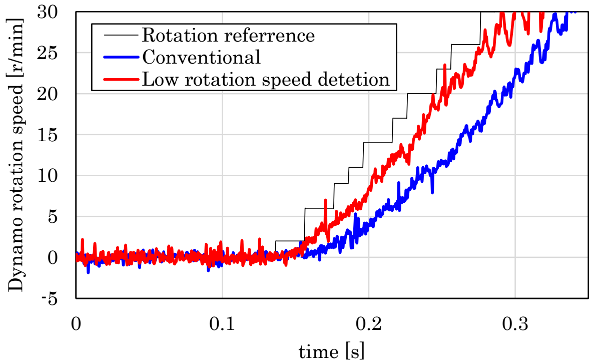

Fig. 3 Comparison of turning from zero speed

Fig. 4 shows the behavior at a constant rotation speed of 10 [r/min]. It can be seen that the fluctuation of rotation speed is suppressed compared to the conventional method. Fig. 5 shows the results of alternating forward and reverse rotation with the rotation speed centered at zero. It can be seen that the rotational speed follows the sine curve of the reference value very well.

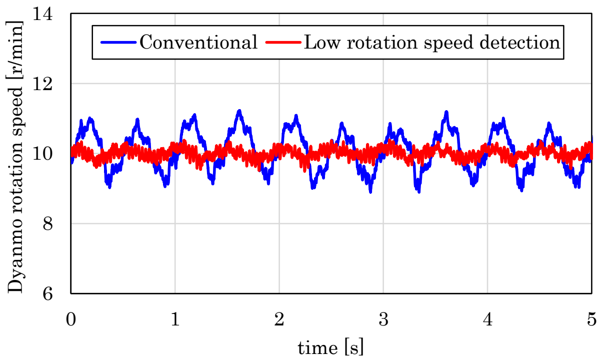

Fig. 4 Stability comparison at low rotational speeds 10 [r/min]

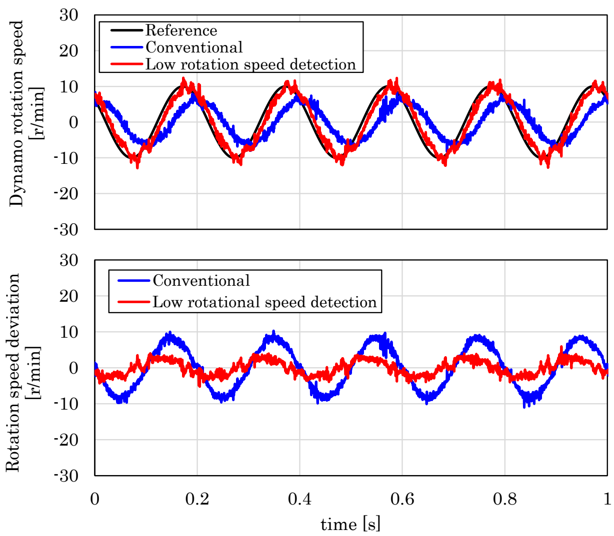

Fig.5 Comparison in CW/CCW switching operation

4. RESULTS OF ACTUAL VEHICLE TEST

The test results of a hub dynamometer with a low rotational speed detector integrated into each wheel are shown. A C-segment electric vehicle was used as the test vehicle.

4.1. Constant vehicle speed

The behavior when the dynamometer is speed-controlled and kept constant at 10 [r/min] is shown in Fig. 6. It can be seen that even when torque is applied from the vehicle, both the rotational speed and torque amplitude are suppressed compared to the conventional method.

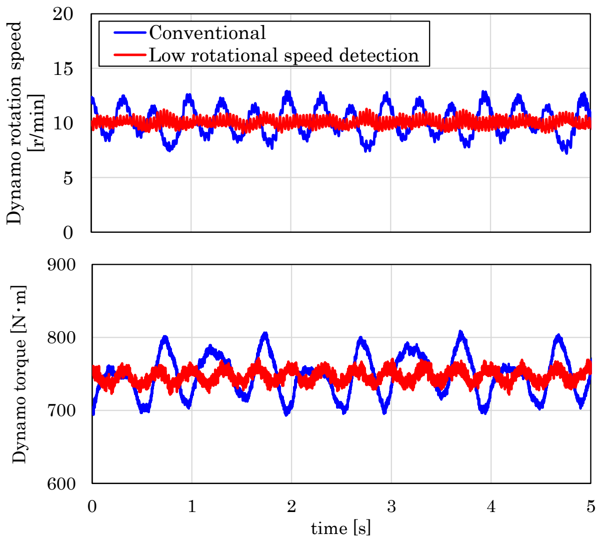

Fig.6 Comparison of constant speed and constant torque application

4.2. Starting a vehicle from a stop

Fig. 7 shows the behavior of rotation speed and torque when starting from a stop. It can be seen that the torque of the conventional system oscillates significantly at the moment of starting. This is because the resolution of the speed signal used as feedback is too rough, and the control system excites equipment vibration. On the other hand, the new method suppresses torque fluctuations and can be adapted to control without excitation of equipment vibration.

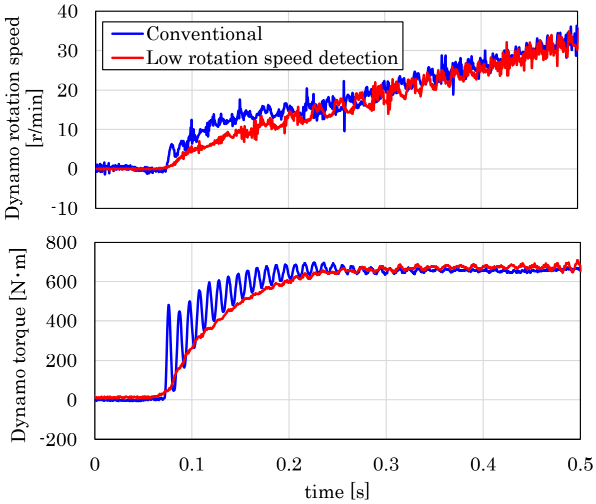

Fig.7 Comparison at startup

4.3. Starting a vehicle on an uphill

Fig. 8 shows the behavior of a vehicle simulating starting on a hill on a hub dynamometer. The vehicle is stopped on an uphill road, the brake is released to reverse the slope, and then the accelerator pedal is turned on to move forward. With the conventional method, there were fluctuations in rotational speed and torque during reverse rotation, and rattling also occurred when switching from reverse to forward rotation. Fig. 9 shows the output of the low rotational speed detector during the switch from reverse to forward rotation. It can be seen that the phases of A and B change smoothly. The unstable behavior of the torque in the conventional method caused the battery current to fluctuate. The new method can suppress the influence on the vehicle control caused by the dynamometer control.

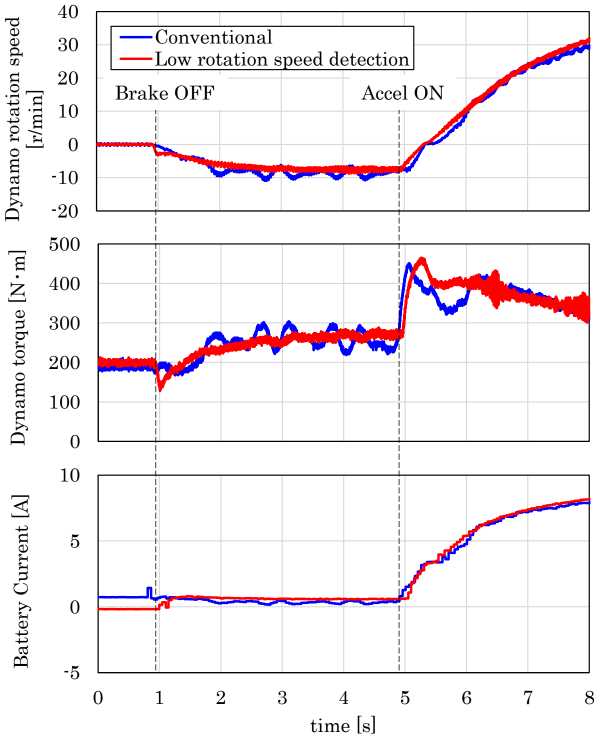

Fig.8 Comparison of starting a hill

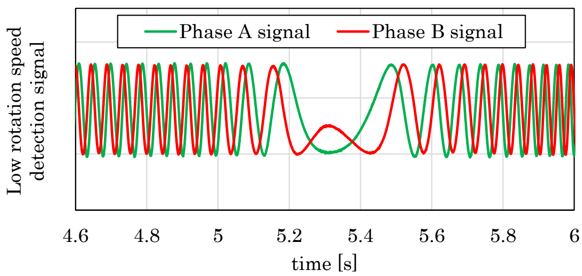

Fig.9 Low rotation speed detector output when switching rotation direction

5. CONCLUSION

In this study, we demonstrated the improvement of operational accuracy of a hub dynamometer in the low-speed range by measuring and controlling low rotational speeds accurately and responsively in a non-contact manner only by adding detector heads and signal processing, without installing a new resolver or high-resolution encoder to the facility. This has shown that test equipment can be renovated to meet the evaluation needs for the development of new electric vehicles without a large investment compared to the conventional test equipment that mainly uses fossil fuels.

In the future, by improving this technology, we would like to expand it to the testing and evaluation needs required for the development of next-generation vehicles such as in-wheel motor vehicles, and continue further research activities to realize a sustainable mobility society and to provide measurement equipment and testing facilities that improve the safety, security, and comfort of people.

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