Control of Drive-Train Bench System for Simulating the Real Vehicle Motion

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***Abstract*— Drive-train bench system is utilized to test power-train components of a vehicle such as transmission, torque converter, etc. In order to simulate the real vehicle motion, it is necessary that dynamometers of the drive-train bench simulates the various road conditions such as dry road surface and snow road surface, etc. To simulate the condition that the vehicle is running on the dry road, it is necessary that the dynamometer is controlled so that the moment of inertia of the output side of the drive-train bench is virtually equal to the moment of inertia of the vehicle. On the other hand, to simulate the snow road surface, it is necessary that the dynamometer is controlled so that the moment of inertia of the drive-train bench is virtually equal to the moment of inertia of the tire. Furthermore, in the brake operation on the snow road surface, braking time changes by how to use brake. Drive-train bench simulates the brake operation of real vehicle by controlling the dynamometer. In this paper, a control design method of the drive-train bench system is proposed for simulating various road conditions and brake operation.**

I. INTRODUCTION

Since the request of environmental performance for vehicle is increasing in recent years, it is necessary to shorten the development time of vehicle components such as transmission and torque-converter. Drive-rain bench system is a test system for performing the durability test or transmission efficiency measurement of the transmission and the torque converter. A conventional drive-train bench simulates the running condition that the tire grips the road. However, as for the real vehicle, a tire may slip depending on a road surface condition. The load torque of the transmission greatly varies whether a tire slips or a tire grips. Furthermore, the load torque greatly varies by break operation.

To shorten the development time of vehicle components, it is necessary that the drive-train bench can simulate the various running conditions.

The conventional control method of the drive-train bench is reported[1], and its control method cannot simulate the running conditions that the tire slips. References[2] and [3] propose the control method how an engine test bench simulates the real vehicle.

In this paper, the control design method of the drive-train bench is proposed for simulating the various running condition. The proposed control method enables to simulate the following phenomena which are impossible by the conventional control method.

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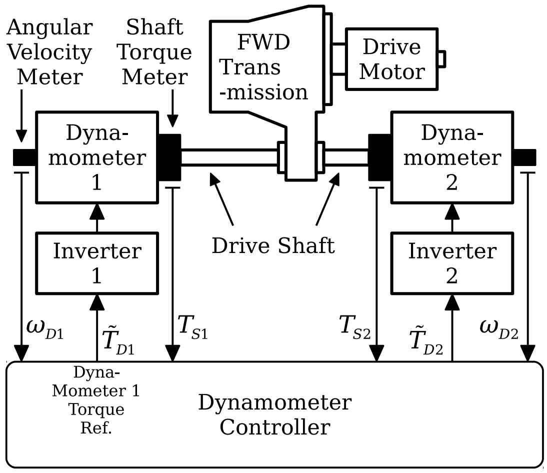

Fig. 1. System configuration

- Simulation of the continuous change between the slip run and the grip run.
- Simulation of the change of the tire stop time by how to operates break.
- Simulation of the change of the load torpue of the transsmission by how to operates brake.

II. SYSTEM CONFIGURATION AND CONTROL OBJECTIVE

Figure 1 shows the mechanical configuration and the control system of the drive-train bench to test a Front-Wheel-Drive (FWD) transmission and drive shaft. A motor substituting for the engine is installed in the input side of the transmission. The control design method of this motor was proposed[4].

Dynamometers substituting for the tire and vehicle body are installed in the output side of the drive shaft. A torque meter for measuring the torsional torque of the drive shaft (shaft torque) is installed between the drive shaft and the dynamometer. Dynamometer controller calculates the torque reference of the dyanmometer from the shaft torque and the angular velocity. The dynamometer torque reference is input into an inverter, and the inverter controls the dynamometer torque.

Figure 2 shows the mathematical model of mechanical system of drive-train bench, where T_M is the torque of the drive motor, J_M is the moment of inertia of the drive motor, g is the gear ratio of the transmission, T_{S1} is the drive shaft torque of the dynamometer 1, T_{D1} is the torque of the dynameoter 1, ω_{D1} is the angular velocity of the dynamometer

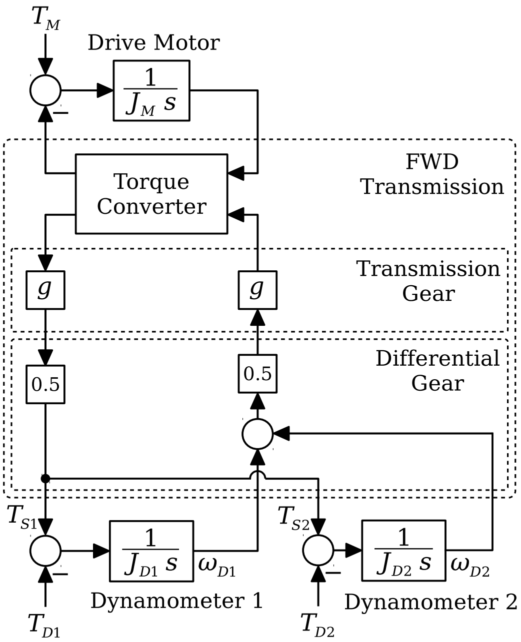

Fig. 2. Mathematical model of mechanical system of drive-train bench

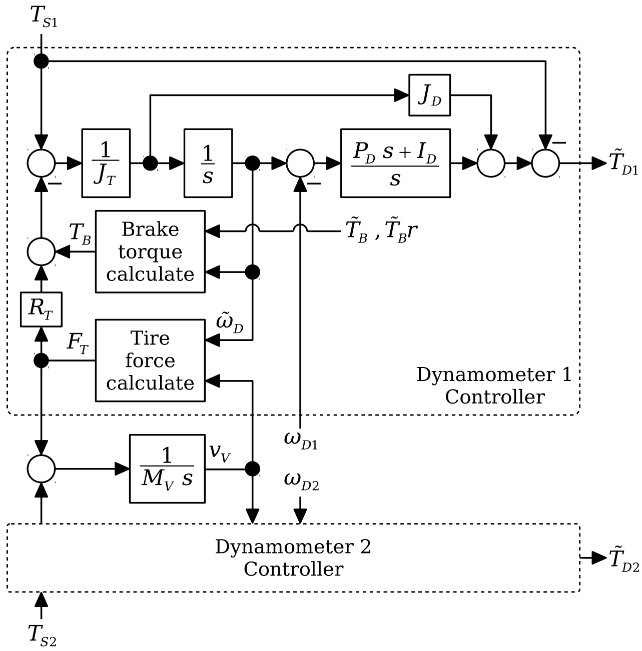

Fig. 3. Slip simulation control

1, J_{D1} is the moment of inertia of the dynamometer 1. 'Toque Converter Model' has two input signals (impeller speed and turbine speed), and two output signals (impeller torque and turbine torque). 'Differential Gear Model' divides input torque into dynamometer 1 and 2 equally. and mean speed of dynamometer 1 and 2 is input into the transmission.

The low inertia dynamometer is applied, whose moment of inertia is about 2.5kg.m^2. On the other hand, the moment of inertia of the tire is about 0.5kg.m^2 per one tire, and the moment of inertia of the vehicle is over 100kg.m^2. Therefore, to simulate the slip run and the grip run, it is necessary that the dynamometer is controlled so that the moment of inertia of the drive-train bench is from 0.5 to 50kg.m^2. The moment of inertia that the dynamometer simulates varies according to the simulating road condition.

Brakes operation is simulated by applying decelerating torque to the dynamometer torque reference. However, the dynamometer may reverse after the dynamometer stops when constant decelerating torque continues being applied. To prevent the dynamometer from revese revolution, the break operation needs feedback control of the angular velocity of the dynamometer. The vibration of drive shaft or the tire stop time varies according to the break operationg condition (strong or weak, and quick or slow).

III. CONTROL METHOD FOR SIMULATING THE MOMENT OF INERTIA OF REAL VEHICLE

Figure 3 shows the block diagram of the control system for simulating the moment of inertia of real vehicle by controlling dynamometers. The conventional control method[1] is assumed that the angular velocity of the tire(= the angular velocity of the dynamometer) is equal to the vehicle speed, but the proposed control method distinguishes the tire speed and the vehicle speed.

'Tire force calculate' shown in Fig.3 calculates the driving force per one tire from the angular velocity of the tire and the vehicle speed[5]. 'Brake torque calculate' is a controller for simulating the break operation of the real vehicle by controlling the dynamometer. Equations (1) and (2) show how to calculate the tire force F_T. J_T is the moment of inertia of the tire of the virtual vehicle which the dynamometer simulates. R_T is the radius of the tire of the virtual vehicle which the dynamometer simulates. $\tilde{\omega}_D$ is the angular velocity reference of the dynamometer. v_V is the speed of the virtual vehicle. N_z is the normal weight force per one tire. μ_{MAX} is the maximum friction coefficient which varies according to the simulating road condition. Function $\mu(\lambda)$ is non-linear function which calculates the normalized friction coefficient from the slip ratio λ. Figure 4 is an example of the function $\mu(\lambda)$. In this example, μ has maximum value at $\lambda = 0.2$, so it becomes grip mode at $0 \leq \lambda \leq 0.2$ and slip mode at $0.2 \leq \lambda \leq 1$. μ_{MAX} is about 1.2 in the case of dry road, about 0.8 in the case of wet road and about 0.2 in the case of snow road.

$$\lambda = \frac{R_T \cdot \tilde{\omega}_D - v_V}{\max(R_T \cdot \tilde{\omega}_D, v_V)} \tag{1}$$

$$F_T = N_z \cdot \mu_{MAX} \cdot \mu(\lambda) \tag{2}$$

'J_D' in Fig.3 denotes a feedforward gain from the angular acceleration of the virtual vehicle tire to the dynamometer torque reference, and its value is equal to the moment of inertia of the dynamometer. The control for simulating the slip condition and the grip condition are stabilized at the same time by the feedforward control. Figure 5 and 6 show the effects of the feedforward control. These plots are the

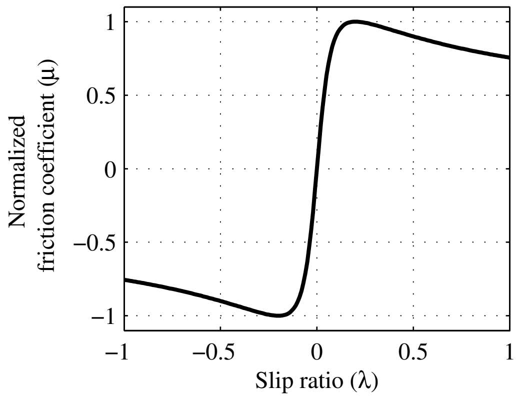

Fig. 4. Normalized friction coeffient and slip ratio

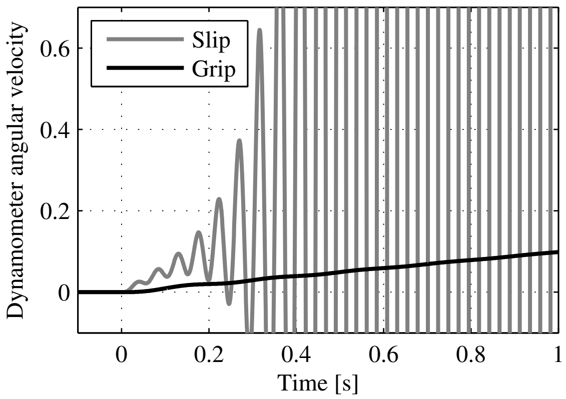

Fig. 5. Without feedfowarad control

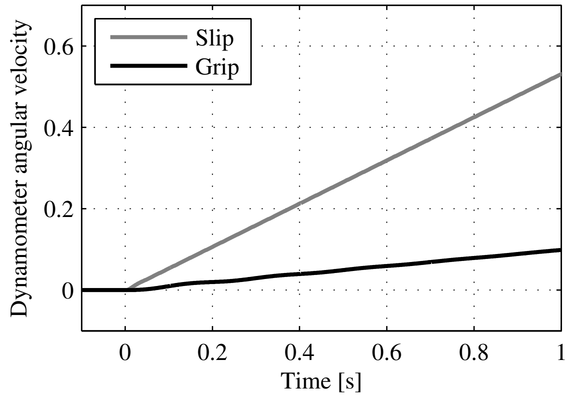

Fig. 6. With feedfowarad control

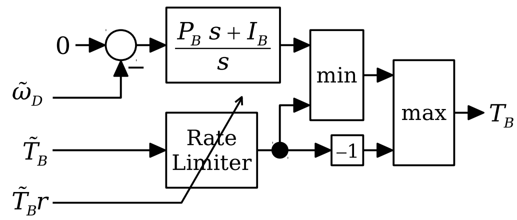

Fig. 7. Brake control

step response from a torque of a drive motor to the angular velocity of the dynamometer(=the angular velocity of the virtual vehicle tire). Figure 5 shows the step response from a torque of a drive motor to the angular velocity of the dynamometer in the case where the feedforward control was not employed. The control for simulating the slip condition becomes unstable in this case. On the other hand, Fig.6 shows the step response from a torque of a drive motor to the angular velocity of the dynamometer in the case where the feedforward control was employed. The control for simulating both the slip condition and the grip condition is stable.

IV. CONTROL METHOD FOR SIMULATING THE BRAKE OF REAL VEHICLE

Figure 7 shows the block diagram of the control system for simulating the brake operation of real vehicle by controlling dynamometers.

The reference signals of break control are the maximum break torque($\tilde{T}_B$) and the limiter of the increasing rate per time of break torque($\tilde{T}_B r$). The break controller works so that the angular velocity reference of the dynamometer($\tilde{\omega}_D$) becomes zero. The maximum break torque($\tilde{T}_B$) simulates the strength of the break operation, and the limiter of the increasing rate per time of break torque($\tilde{T}_B r$) simulates the speed of the break operation.

V. SIMULATION RESULTS OF PROPOSED CONTROL METHOD

In this section, simulation results are shown which compare the conventional control method and the proposed control method. These simulations are implemented by connecting the drive-train bench model shown in Fig.2 with the dynamometer control model shown in Fig.3 and Fig.7. Simulink on Windows 7 was used for simulation.

The control result by the conventional control method[1] is shown in Fig.8, where the break controller shown in Fig.7 is used. This control methods cannot simulate the slip run because the control method does not have the tire model and it is assumed that the angular velocity of the tire is equal to the vehicle speed.

The control result by the proposed control method is shown in Figs.9 and 10. The vehicle transfers from grip run to slip run at about 7[s] according to the maximum friction coefficient (μ_{MAX}) decreases. Figure 9 shows the control result of simulating a wheel-lock and a pulsatile torque vibration of drive shaft by strong brake operation on low friction road surface. Figure 10 shows the control result of simulating a non-slip vehicle motion by weak brake operation. Because of weak break operation, there is not a torque vibration of drive shaft and a tire does not slip. As a result, braking time become short.

The proposed control method enables simulating the running condition on various road surface and brake operation.

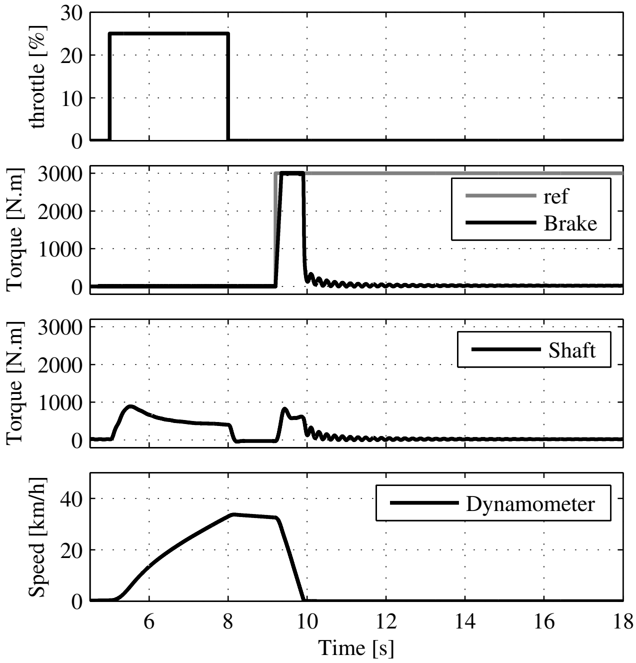

Fig. 8. Simulation result of conventional control methed

VI. CONCLUSIONS

The conventional control method could not simulate the slip run on low friction road surface, because it did not have the tire model and assumes that the angular velocity of the tire is equal to the vehicle speed. In this report, we proposed the control method of the drive-train bench for simulating the slip run and break operation of real vehicle. An experiment in comparison with the real vehicle motion is a future problem.

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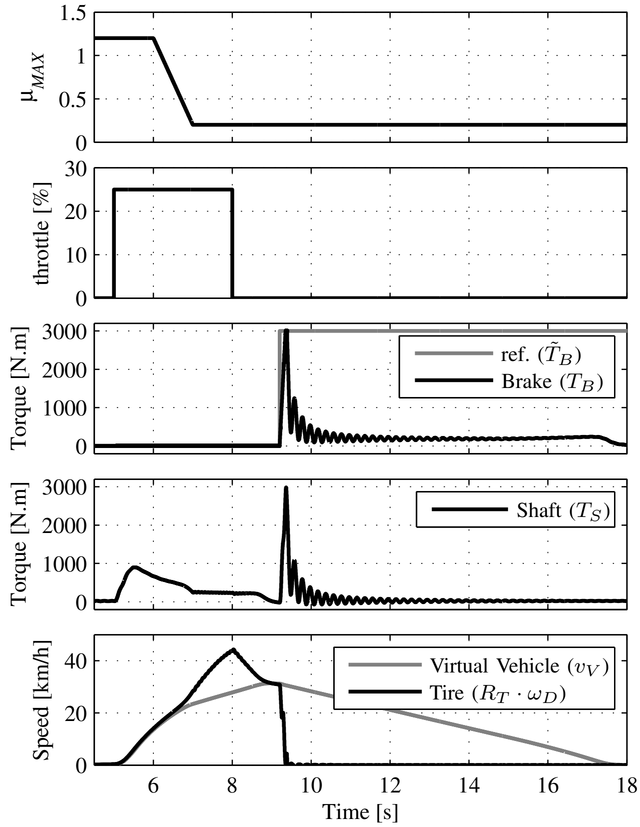

Fig. 9. Simulation result of proposed control methed (a)

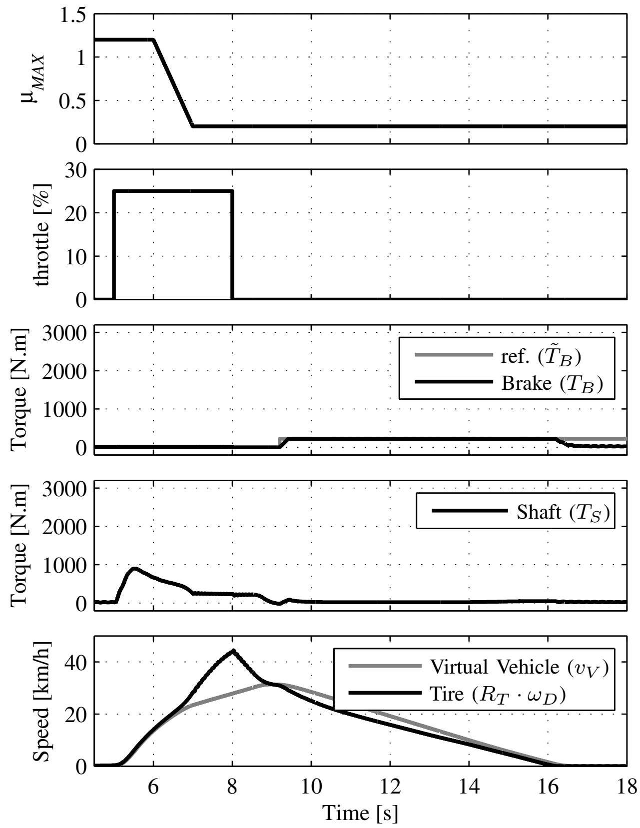

Fig. 10. Simulation result of proposed control methed (b)