Control Technologies for Drivetrain Bench to Simulate Real Road Loads

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Abstract

We developed a control technology to reproduce various real road loads on test models by using the output shaft dynamometer of the drivetrain bench. Compared with our conventional control technologies, the following simulation controls are newly available:

(1) Simulation control of tire inertia

(2) Tire slip on a low μ road

(3) Wheel lock by heavy braking on a low μ road

(4) Excessive drive shaft torque in the case of wheel lock

1 Preface

With the rising demand for environmental performance of automobiles, a shorter development period for the automotive components such as transmissions, torque converters, etc. has been requested increasingly. The dynamometer is equipment used for various testing on automobiles and key components. In automotive industries, the advanced R&D programs to keep up with such demands are on the rise. This prompted that dynamometers be required to have more advanced technologies. To meet such demands, we are working on to advance control technologies for the dynamometer by model-based control.

This paper introduces our dynamometer control technologies to realize real road load simulation as actually exerted on the transmission and other components. The tests are conducted at the drivetrain bench for various testing of transmissions and torque converters.

2 Outline of Control Method

A conventional drivetrain bench is devised to simulate the only running condition in which the tire grips the road. In actual road running, however, a slipping tire can occur. The load exerted on the transmission while tires are slipping greatly differs from a case when tires are gripping the road. In addition, the load exerted on the transmission can be greatly changed by the manner in braking.

To reduce the development period for transmissions and torque converters, it is necessary to reproduce various running conditions at the drivetrain bench.

For the output shaft dynamometer of the drivetrain bench, we have recently developed a control method to simulate various running conditions. We will introduce the outline of this control method. The newly developed method can reproduce the following phenomena that were not possible by conventional control methods:

(1) Simulation of continuous changes in slip running and grip running

(2) Simulation of changes in tire stop conditions according to the manner of braking

(3) Simulation of changes in loads exerted on transmissions according to the manner of braking

3 System Configuration

Fig. 1 shows a system configuration of the drivetrain bench to test the transmissions and drive shafts of Front-engine, Front-drive (FF) cars. On the input side of a transmission, a dynamometer is installed to work as a car engine replacement. We previously reported the method of control with this dynamometer to make torque excitation equivalent to that of a car engine by other our technical journal[(1)].

On the output side of a drive shaft, another dynamometer is installed to work as a set of tires and car body. Between the drive shaft and the output-shaft dynamometer, there is a shaft torque

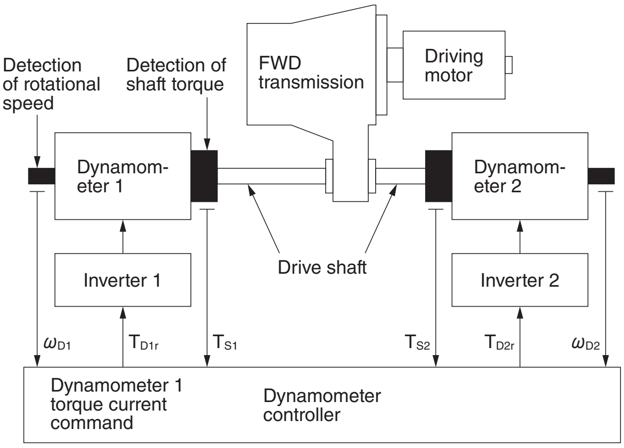
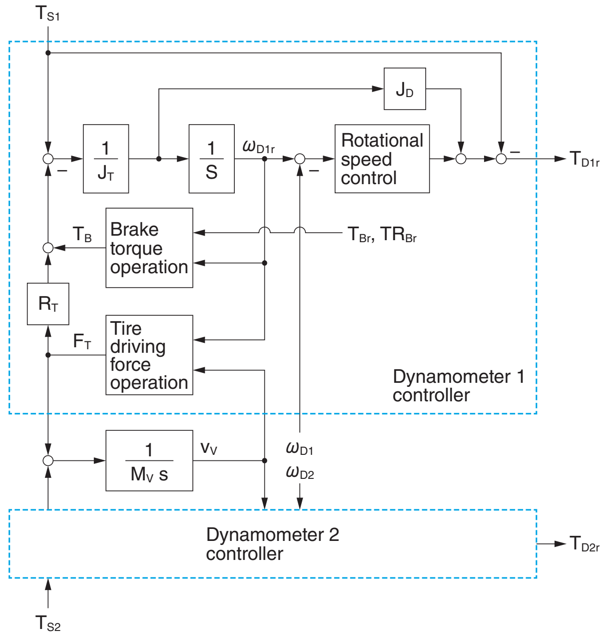


Fig. 1 System Configuration

An example of the mechanical configuration of a drive train bench is shown for the Front Wheel Drive (FWD) transmission. In some cases, a car engine is used instead of a driving motor.



J_T: Virtual moment of inertia of tire
R_T: Virtual turning radius of tire
M_V: Virtual vehicle body mass
J_D: Moment of inertia of dynamometer
ω_{D1r}: Angular velocity command of dynamometer
T_B・T_{Br}・TR_{Br}: Signals relating to virtual vehicle brakes
F_T: Driving force per driving wheel of virtual vehicle
V_V: Virtual vehicle velocity

Fig. 2 Slip Control Circuit

A control circuit is shown, intended to simulate tire-slipping phenomena. Inertia of tires and car body is distinguished for control.

meter that measures the torsional torque (shaft torque) of the drive shaft.

The role of the controller is to calculate a command value of dynamometer torque based on the feedback values of the shaft torque and dynamometer rotational speed. An output of the dynamometer torque command value is sent to the inverter, which then functions to make torque controls for the dynamometer.

4 Dynamometer Control System to Simulate Various Road Running

While the drive shaft torque is detected with a shaft torque meter, the goal of dynamometer control depends on how a response of dynamometer rotational speed is implemented. In order to simulate a condition of complete tire idling, it is necessary to make a simulated control by setting up a tire's moment of inertia approximately at 0.5kg·m^2. If simulation is needed to create a condition of a tire gripping, simulated control of the moment of inertia over 100kg·m^2 is required. Where a low-inertia type of dynamometer is adopted, a simulated control of moment of inertia has to be carried out continuously within the range of a fraction times to some tens of times the dynamometer's moment of inertia.

Fig. 2 shows a slip control circuit. A moment of inertia from the dynamometer as seen from the side of driveshaft is simulation-controlled into another moment of inertia corresponding to the value of running on various kinds of roads. In the case of conventional controls at the drive train bench, it was assumed that tire rotational speed (= dynamometer's number of rotational speed) is equal to vehicle velocity. For a control circuit in Fig. 2, however, the tire rotational speed (= dynamometer's number of rotational speed) is distinguished from the vehicle velocity.

The "tire driving force operation" block is in charge of the calculation of driving force per driving wheel according to the road surface condition. This is based on the tire rotational speed and vehicle velocity. The "brake torque operation" block is a control circuit used to simulate various kinds of braking operation under dynamometer control.

5 Dynamometer Control System to Simulate Various Braking Operations

When we adopt actual car driving conditions, in the event we brake weakly, strongly, slowly, or suddenly, big differences are caused in the condition of tire slip condition and drive shaft vibrations.

Fig. 3 shows a brake control circuit by which various kinds of braking actions are simulated. Inputs of brake torque command T_{Br} and gradient

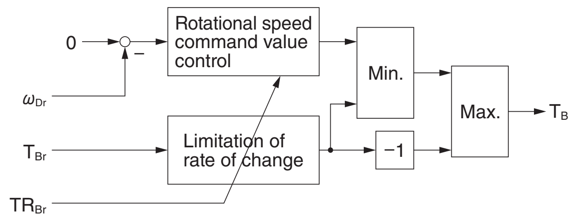


Fig. 3 Brake Control Circuit

A control circuit to control braking strength and speed is shown.

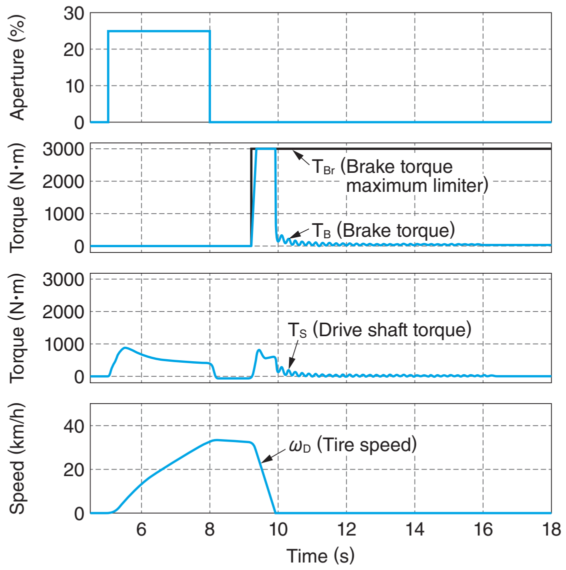


Fig. 4 Result of Simulation by Conventional Control Circuit

In a conventional control circuit, there is no distinction of tire speed and vehicle velocity. It is understood that the tire always grips the road.

command TR_{Br} are entered in the brake control circuit so that the dynamometer rotational speed command ω_{Dr} is turned into 0. The brake torque command T_{Br} functions as a brake torque maximum limiter. The torque level enough to stop dynamometer rotational speed is a torque output from the brake control circuit in **Fig. 3**. The rate limiter is used to reduce the changing rate of input T_{Br} per unit time down to TR_{Br} or lower.

The brake torque command T_{Br} is used to simulate the intensity of braking and the brake torque gradient command TR_{Br} simulates the pace of the braking operation.

6 Result of Simulation by Proposed Approach

Fig. 4 shows the result of simulation by the conventional control circuit. Since there is no distinction of tire rotational speed and vehicle velocity in the case of the conventional control, tire slip phenomena cannot be reproduced.

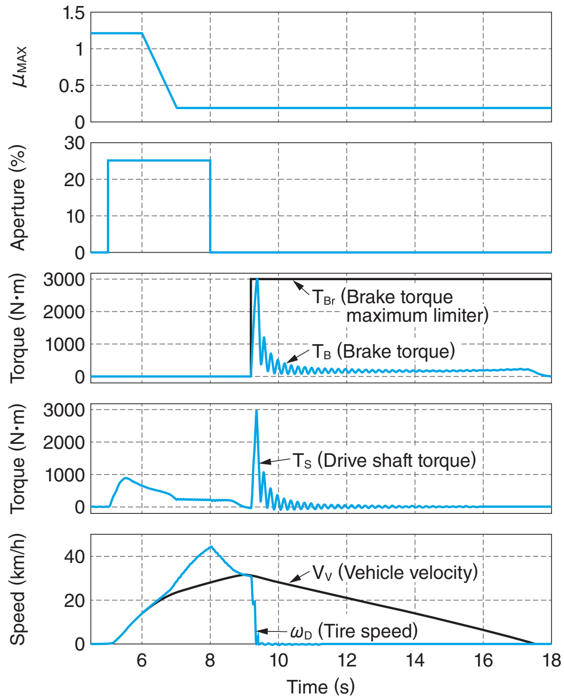


Fig. 5 Result of Simulation by Slip Control Circuit (1)

In a slip control circuit, there is a distinction of tire speed and vehicle velocity. The wheel lock phenomena can, therefore, be simulated.

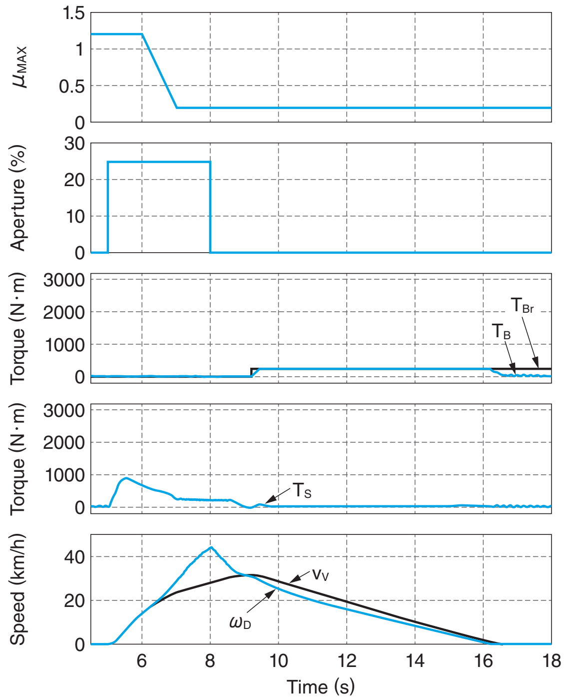


Fig. 6 Result of Simulation by Slip Control Circuit (2)

In the slip control circuit, it is possible to simulate that when brakes are gently applied, there will be tire slipping.

Fig. 5 and **Fig. 6** show the result of simulation by the control circuit proposed for this time. When maximum frictional coefficient μ_{MAX} is lowered, grip running (tire speed ≒ vehicle velocity) is turned into slip running (tire speed > vehicle velocity) at around 7 seconds. After that, sudden braking is applied as shown in **Fig. 5** and the occurrence of a wheel lock phenomenon is reproduced. In the case of a wheel lock on a slip road surface, great pulse-state changes in drive shaft torque are reproduced. In **Fig. 6**, tires are gripped by the effect of the accelerator switched off and the state of slow braking is reproduced. Since braking is weak, no heavy torque is exerted on the drive shaft. Since there is no condition of a wheel lock, the time required to stop is shortened.

As stated in (1) through (3) of Chapter **2**, various phenomena considered to occur during the running under various conditions on the road surface are reproduced by our proposed control method.

7 Postscript

Since there was no distinction of tire speed and vehicle velocity in the case of conventional control systems, it was impossible to reproduce the tire-slipping phenomena. We proposed a new control method in order to reproduce the tire-slipping phenomena to simulate the braking actions of a real vehicle. By this simulation, we could confirm the effects by our newly proposed control method.

Going forward, we will work on developing dynamometer control technologies suitable in order to reproduce the various actual road loads.

《**Reference**》

(1) Takao Akiyama, Kazuhiro Ogawa, Yoshimasa Sawada: "Shaft Torque Excitation Control for Drivetrain Bench," Meiden Review Vol.166, 2016/No.1, pp.28-32