New Dynamometer System for Wheel Axle of Drivetrain Bench

Ryo Kaneko,
Wataru Miyazaki

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Abstract

As the vehicle drive control technology for safety measures becomes more sophisticated, the drivetrain benches used to test it are required to be able to simulate various road conditions using wheel axle dynamometers. In order to meet this demand, it is necessary to increase the control response of the dynamometer, which requires new technology in terms of both mechanical equipment and control technology.

This time, we have developed a new low-inertia dynamometer as a mechanical device. The outer diameter of the rotor core has been reduced to achieve low inertia. Additionally, this dynamometer has improved layout efficiency by being smaller in the width direction and by concentrating the connection with auxiliary equipment on one side. As a control technology, we have developed a control method that allows response adjustments that take frequency characteristics into consideration. With this control method, the frequency characteristics of electrical inertia control are improved compared to the conventional method. These features have made it possible to apply loads to the specimen under various road surface conditions that are even more similar to actual roads.

1 Preface

In recent years, vehicle driving force control technology has become increasingly sophisticated in vehicles in order to improve safety technology and improve vehicle operability. As a result, the market requirements for vehicle drive system evaluation testing machines (drivetrain benches) are also becoming more sophisticated.

This paper introduces the development of a new low-inertia dynamometer that is connected to the wheel axle of a drivetrain bench and can perform simulation tests of various road conditions and driving conditions. We also introduce its newly developed control technology.

2 Features and Specifications of Low-Inertial Dynamometer, PMDY-LV300

Fig. 1 shows the external appearance of Permanent Magnet Dynamometer-Low Velocity 300 (PMDY-LV300). PMDY-LV300 has the following features:

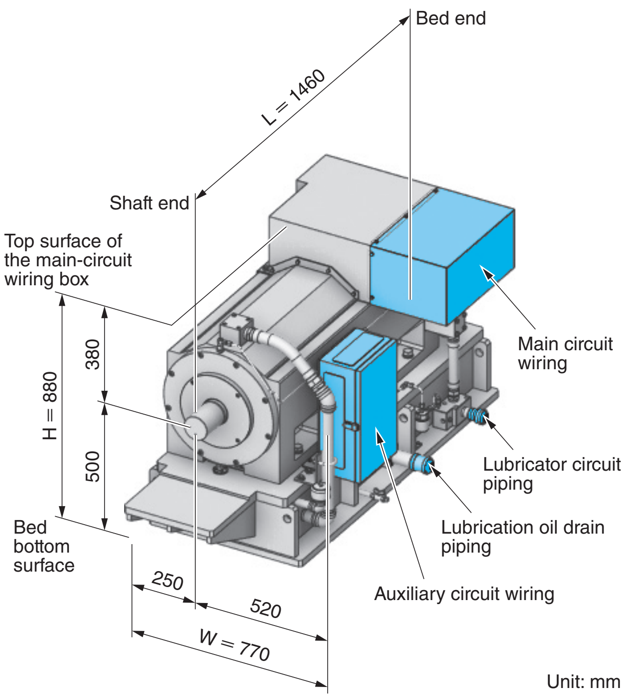


Fig. 1 External Appearance of PMDY-LV300

Since the assorted arrangement of connection points for other equipment are made on one side (on the right side of the diagram), the equipment placement is easier.

Table 1 Standard Specifications

Low inertia is featured in the specifications of PMDY-LV300.

Item		PMDY-LV300
Continuous rating	Absorption capacity	300 kW
	Driving capacity	300 kW
Maximum torque	Absorption torque	3000 N·m
	Absorption torque (at Max. revolving speed)	955 N·m
	Driving torque	3000 N·m
	Driving torque (at Max. revolving speed)	955 N·m
Base revolving speed		955 min^{-1}
Maximum revolving speed		3000 min^{-1}
Moment of inertia (PMDT-LV alone)		0.8 kg·m^2
Overload rating at 955 min^{-1}	Percentage	150%
	Time	60 s
	Absorption capacity	450 kW
	Driving capacity	450 kW
	Absorption torque	4500 N·m
	Driving torque	4500 N·m
Maximum acceleration/ deceleration	At continuous rating	35,800 min^{-1}/s
	At overload rating	53,700 min^{-1}/s
External dimensions		W770 × H880 × L1460 mm
Center height		500 mm
Approximate mass		1700 kg

Table 2 Non-Standard Specifications

As an optional offer, specifications for excitation torque are available.

Item	PMDY-LV300	
Excitation performance at 955 min^{-1}	Excitation frequency	Excitation torque amplitude
	10 Hz	±3000 N·m or below
	20 Hz	±1500 N·m or below

(1) This is an oil-immersed AC electric dynamometer that uses a permanent magnet in the rotor.
(2) High response (improved acceleration/deceleration performance) was achieved by lowering the inertia. It can handle simulation tests of various road conditions and driving conditions.
(3) Compact design (compact design in the width direction of the dynamometer) and assorted arrangement of connecting points (with other equipment) on one side. This connection refers to main circuit and auxiliary circuit wiring and oil supply/drainage circuit piping. This one side arrangement makes equipment arrangement easier.

Table 1 shows the standard specifications of PMDY-LV300. Table 2 shows the non-standard

Table 3 Accessories (Oil Supply System)

For PMDY-LV300, main body cooling and bearing lubrication are carried out by using lubricator unit.

Item		Lubricator unit
Amount of lubrication oil		80 L/min
Lubrication oil pressure		0.5 MPa Max.
Cooling water	Water temperature	32℃ or below
	Water pressure	0.2∼0.5 MPa
	Flow rate	100 L/min
External dimensions		W1600 × H1250 × D380 mm
Approximate mass		500 kg

specifications. Table 3 shows the specifications of the oil supply system for PMDY-LV300 main body cooling and bearing lubrication. Vibration performance is necessary for bench-based simulation of drive shaft vibration caused by tire slip and grip phenomena when driving on a bumpy road.

3 Featured Technologies of PMDY-LV300

3.1 Going Low Inertia

(1) This dynamometer uses a permanent magnet rotor to reduce the size of the rotor core. We did electromagnetic field analysis and structural analysis in order to create a shape that achieves both the required electrical properties and mechanical strength. Detailed electromagnetic field analysis and structural analysis were carried out. As a result, we were able to reduce the outer diameter of the rotor core and achieve low inertia.
(2) To achieve the development goal of high torque, a larger rotating shaft diameter is advantageous. To achieve low inertia, a smaller rotating shaft diameter is advantageous. The optimal shaft diameter was selected to achieve both the target maximum torque and low inertia. The maximum torque shown in Table 1 was achieved.

3.2 Compact Design (Compact Design in Width Direction of Dynamometer)

(1) Through electromagnetic field analysis, we created a shape that satisfies the electrical characteristics and winding structure design requirements. This has made it possible to reduce the outer diameter of the stator core.
(2) By making assorted arrangement on the connection points with other equipment on one side and reducing the width dimension on the other side,

we have achieved external dimensions that makes equipment layout arrangement easier. The main connection points with other equipment are: the main circuit and auxiliary circuit wiring, and the oil supply and drainage circuit piping, which is connected to the oil supply system.

4 Features of New Control Method

Conventional control circuits were configured with Proportional Integral (PI) control that can adjust the proportional gain and integral gain, but the degree of freedom in gain adjustment is limited, which makes it difficult to get close to the target control response. The new control method improves the degree of freedom in adjustment by adding a correction circuit and a phase adjustment circuit to the conventional PI control. **Fig. 2** shows the configuration of this control.

Fig. 3 shows a comparison of the frequency characteristics of the conventional method and the new method. When evaluating control characteristics using frequency characteristics, the characteristics of the vehicle inertia and tire inertia (hereinafter referred to as "setup inertia") that are desired to be simulated can be reproduced in the low frequency band. Unfortunately, as the frequency band approaches the high frequency band, the characteristics shift to the characteristics of the dynamometer inertia. In conventional control circuits, the "anti-resonance point" occurs in the band where the characteristic of setup inertia changes to that of dynamometer inertia. There was a "sharp drop" of gain, but a control circuit that only adjusted the PI gain could not compensate for this phenomenon. The newly developed control system has more adjustment elements than conventional control circuits, making it possible to make adjustments closer to ideal frequency characteristics. It can be confirmed that the frequency response characteristics of the new control circuit do not have a "sharp drop" seen in the conventional PI control system and there is a smooth transition from the set inertia to the dynamometer inertia characteristics.

Fig. 4 shows a comparison of torque waveforms of the conventional control method and the new control method. The torque to be evaluated is the drive shaft torque in a two-inertia system in which two inertia bodies, the engine and the dynamometer, are connected by a drive shaft and the dynamometer inertia is derived as the setup inertia. The setup inertia serves as the evaluation criteria as the target torque detection. It is said that in the waveform of the conventional control method, a phase shift can be seen between the target torque detection and the control torque detection. No phase shift was observed with the new control method, indicating that the detected torque follows the target torque. This shows that the new control method can make the engine torque waveform, the state in which the torque oscillates, more closely resemble the waveform of an actual vehicle. Furthermore, when we check the speed deviation, which is the difference between the target speed determined from the set inertia and the detected speed, we can see that the new control method has less increase or decrease in deviation than the conventional control method, and is able to follow more stably.

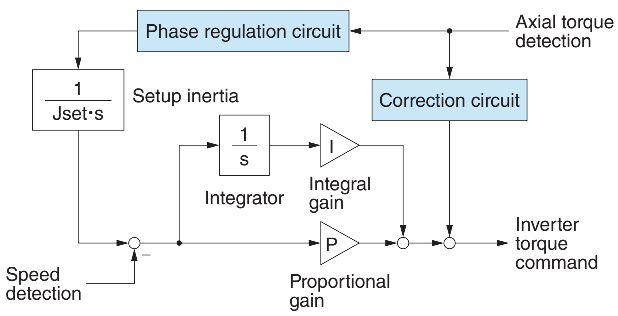


Fig. 2 Configuration of New Control Method

The degree of freedom for adjustment is raised by adding compensation and phase regulation circuits to a conventional PI control method.

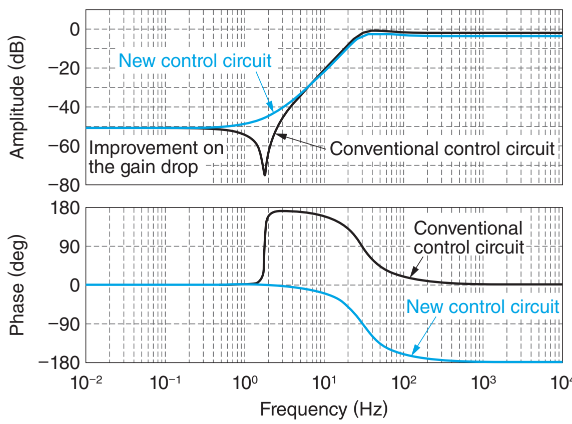
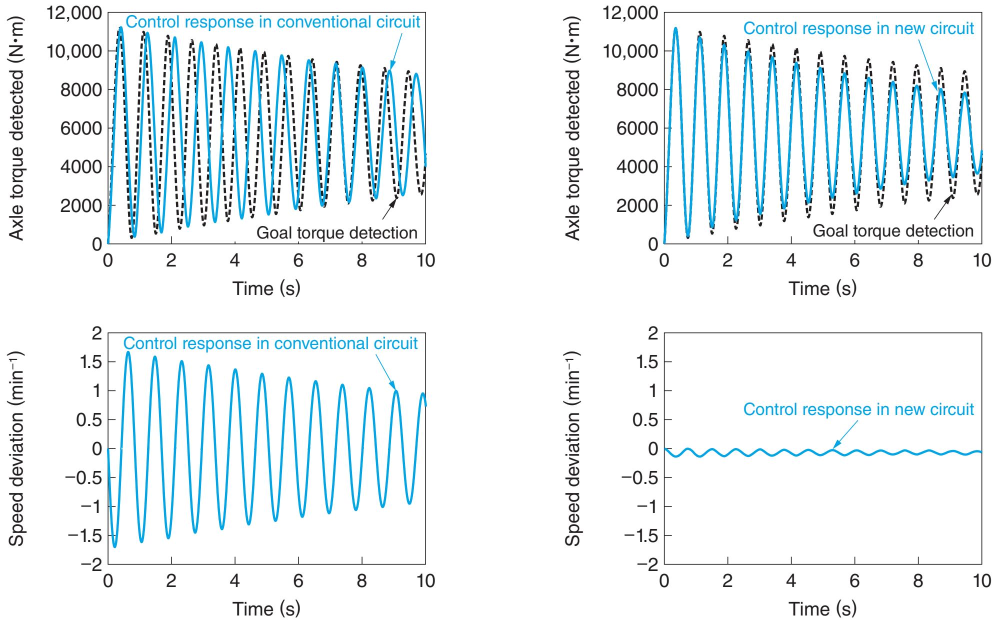


Fig. 3 Comparison of Frequency Characteristics of Conventional Method and New Method

In conventional method, it shows a band of a sharp drop of gain when changing over from low-frequency setup inertia to high-frequency dynamometer inertia. In the case of the new method, however, there is no drop of gain and smooth conditional transfer can be attained.



(a) Conventional circuit (b) New circuit

Fig. 4 Comparison of Torque Waveforms of Conventional Control Method and New Control Method

In the case of a conventional system, the level of speed deviation tends to be high because of a phase shift from the goal level. For the new method, however, the phase shift is minimal and favorable goad level pursuit is achieved. The speed deviation is also minimal.

5 Improvement of Road Driving Conditions Reproduction

This new control method can reproduce the torque fluctuations that occur when driving on slippery or off-road surfaces. When the tires are gripping the road surface, the magnitude of the acceleration/deceleration force exerted by the vehicle is proportional to the vehicle inertia and is transmitted to the road surface via the tires. When the tires are slipping, the force transmitted to the road surface disappears, and the force exerted by the vehicle becomes proportional to the moment of inertia of the tires. The inertia values of the vehicle in a grip state and the inertia of the tires in a slip state are significantly different. This was dealt with by changing the control gain for each or by switching the circuit configuration itself. In this new control method, we have devised a control circuit configuration that does not cause control to become unstable even when there is instantaneous switching between grip and slip with the road surface, that is, between vehicle inertia and tire inertia. Since this control circuit can be configured with one control circuit for one dynamometer, it can also be applied to a four-wheel independent configuration with four dynamometers. It is also useful for off-road driving where each of the four wheels requires separate inertia control. Stable operation has been confirmed in simulations.

6 Postscript

We introduced the features and specifications of a new low-inertia dynamometer that is connected to the tire shaft of a drivetrain bench. We also introduced as an overview of its control technology. In vehicle drive technology, it is expected that the requirements for test equipment will become increasingly sophisticated in response to electrification.

In the future, we will continue to develop and provide test systems that can contribute to the development of advanced vehicle control technology.