# Introduction of Driveline Test System newly Installed in the Laboratory at HORIBA Kyoto

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Recent automotive vehicles are increasing in sophistication due to the awareness of environment impact. As a result, automatic transmissions with increased gears and CVTs, as well as electrically driven vehicles, HVs and EVs, are expanding. The development of these complex vehicles is making driveline evaluation more important than before. These evaluations focus not only on driveline units, but the power-train system which includes the engine and/or e-motor. This exposition features a flexible driveline test system installed at HORIBA (Kyoto) that can evaluate driveline units, e-motors and power-train systems. The system recognizes HORIBA's capability for technological advancements, to find solutions and satisfy customer needs.

## Introduction

Due to the increase in awareness of environmental impact that vehicles have, development of next generation vehicles, characterized by high energy efficiency and low emission gas, has become more progressive. In the development of these vehicles, it is necessary to evaluate engine performance. It is also necessary to test the "driveline", which is the mechanism that transmits power from the engine to the wheels. Drivelines are becoming increasingly sophisticated due to introduction of transmissions with increased gear counts as well as the Continuously Variable Transmission (CVT). Therefore, viable test systems are crucial to the development of these complex vehicles. Development of electrically driven vehicles, such as Hybrid Vehicles (HV) and Electric Vehicles (EV), is another current trend in automotive development. For these vehicles, the electric motor (E-Motor) is essential because it is a power source. E-Motors, in short, have become more diverse. There are many variations of E-motors serving various functions. For example, there are driving/regenerating motors, regeneration dedicated motors, built-in motors in engines/ transmissions and in-wheel motors. Driveline testing for electrically driven vehicles requires testing of E-motors combined with, for example, automatic transmissions.

In the development of next generation vehicle, test specimens are growing in complexity, causing that test items and calibration have been greatly increased. From the vehicle development process point of view, it is essential to develop engines and transmissions simultaneously and dynamically. Therefore, front loading of development is required much more than before. As a result, flexible features for test systems are in demand, such as adaptability, expandability and a wide range of test component. In February 2013, HORIBA group revamped the functions of the test laboratory in Kyoto in order to meet diverse needs more practically. This paper introduces the new test systems capable of testing both driveline components and E-Motors.

## General Configuration of Evaluation Systems

### Driveline Evaluation Systems

"Driveline" refers to hardware such as transmission and drive shaft that transmits power produced by the engine and/or motor, to the wheels that the vehicle runs on. Control systems of automatic transmissions are often included in drivelines. In driveline development tests, performance and reliability of transmissions are evaluated. However, it must also be test with the engine simultaneously. The time to develop a new powertrain system is often prolonged, due to specification changes by problems which are found during combined test after each unit was completely developed. Thus, driveline evaluation systems, which allow testing of transmissions before engine development is completed, are in demand.

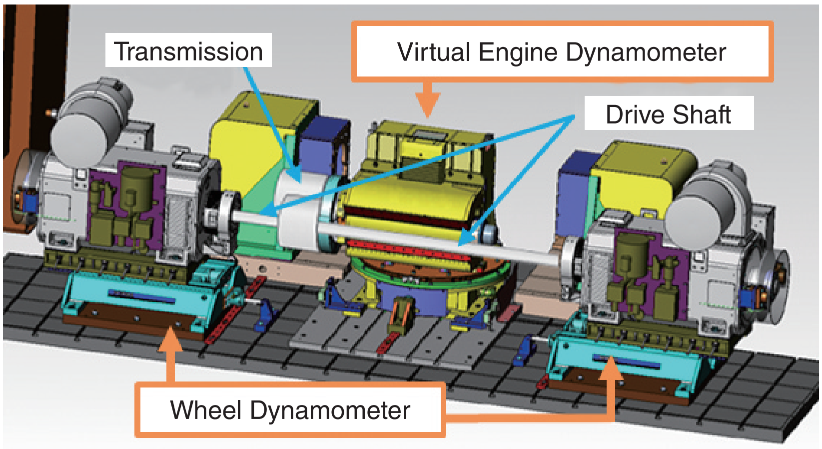


Figure 1 Front Wheel Drive Transmission Test System Layout

Figure 1 shows the standard test system layout for common Front Wheel Drive transmissions. The device located in the middle is called a "dynamometer", which substitutes for the engine and behaves as a "Virtual Engine". "Wheel dynamometers" are installed at both ends of the drive shafts as substitutes for the wheels. Replacing the engine and the wheels with dynamometers makes combined front loading tests possible in the development process.

### E-Motor Evaluation System

Figure 2 is an example of a system layout for performance testing of an E-Motor. E-Motors are installed in Hybrid Vehicles and Electric Vehicles as power sources, like engines, or as electrical generator. In E-Motor testing, dynamometer is also connected to simulate load on the E-Motor. Requirements for E-Motors, including maximum speed and torque range, vary greatly on vehicle specification. In addition, in E-Motor development, it is essential to perform a wide variety of tests, such as efficiency and reliability evaluation, inverter - motor calibration and energy management. Therefore, dynamometers, which have a wide range of control and measurement as well as quick response, are required for E-Motor evaluation systems.

## New System Configuration

### Main Unit in the configuration

Figure 3 shows a system block diagram of the newly introduced test system. In this system, the main dynamometer has specifications which allow it to act as a Virtual Engine and to test E-Motors. The following explains unique features of the main units (①~⑦), represented in Figure 3.

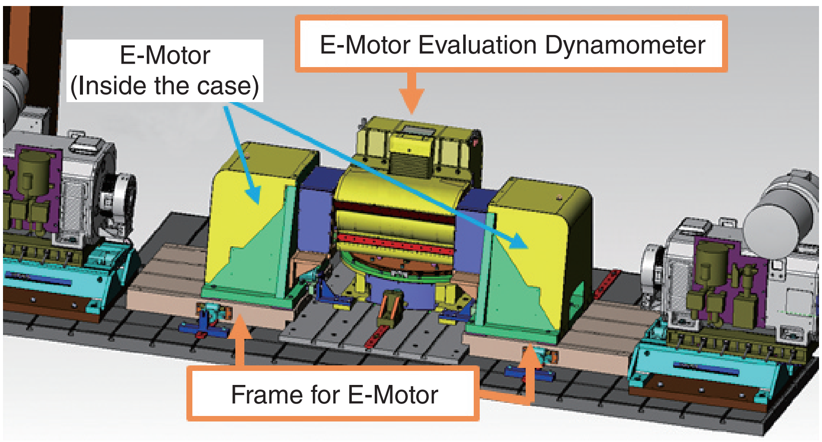


Figure 2 E-Motor Evaluation System Layout

## System Block Diagram of Driveline Evaluation System in Headquarters Test Laboratory

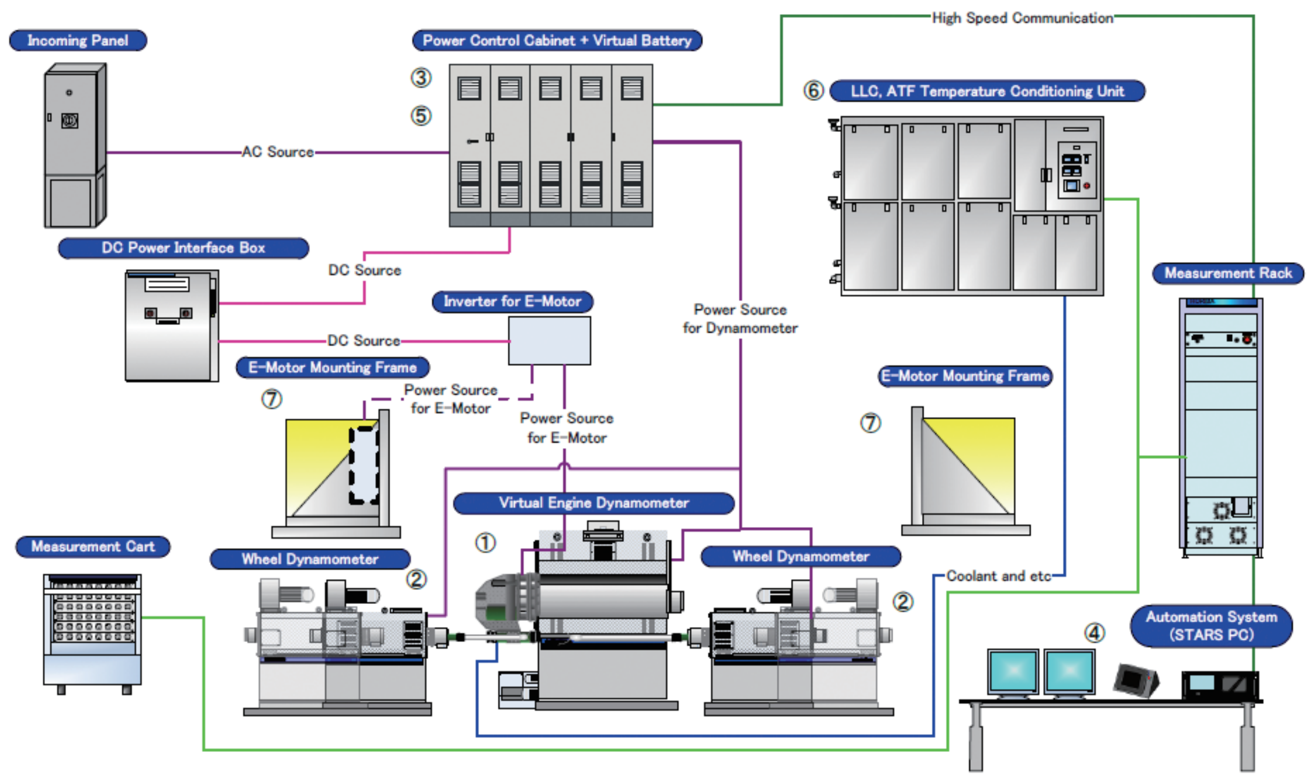


Figure 3 Driveline Test System block diagram in laboratory at HORIBA Headquarters

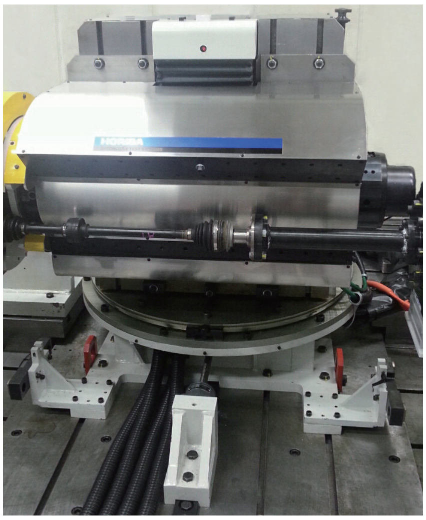

Figure 4 TP-260 Front View

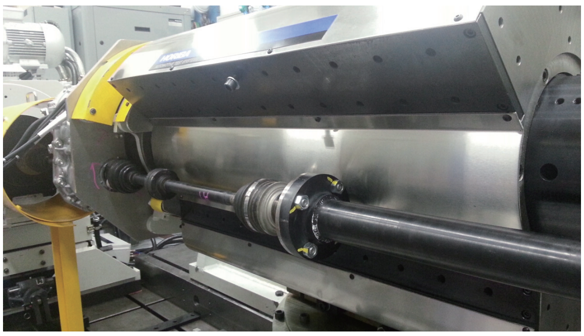

Figure 5 TP-260 Side view

### Low inertia Dynamometer “TP260” (①)

HORIBA’s low inertia dynamometer, TP260, is used for Virtual Engine and E-Motor testing (Figure 4). The performance of the TP260 is rated at 260kW of power and 450Nm of torque. It has very low mechanical inertia which allows the dynamometer to simulate a wide range of inertia together with electric inertia control functions.

The rated power and torque performance of the TP260 as a Virtual Engine is comparable to the output of a 3000cc passenger car. TP260’s small diameter allows the transmission to be installed in the original shaft direction (Figure 5). In addition, a mechanism allows vertical movement of the TP260. This adjusts and simulates height difference between wheel axis and engine. Therefore, TP260 can be used to evaluate driveline systems in condition similar to when transmissions are installed in a vehicle. Engine simulation function, to be mentioned later, is included in control software as well.

The TP260 is a high speed and low inertia dynamometer. Therefore, it is possible to meet the demands in E-Motor testing to operate at twice or more speed than engine and to respond faster than engine. Two E-Motor can be connected at the each ends of TP260, allowing for two E-Motors to be tested simultaneously. This feature helps to reduce development time of E-Motor.

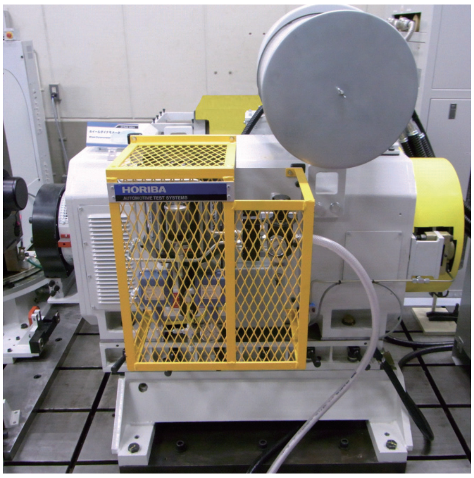


Figure 6 G224 Outline View

### Dynamometer for wheels “G224” (②)

HORIBA G224, as shown in Figure 6, has a rated power of 224kW and maximum torque of 4000Nm. Two of these dynamometers act as wheel dynamometers, absorbing wheel torque. Road load can be simulated by combining mechanical and electrical inertia. This dynamometer has an additional mechanical brake to simulate complete zero wheel speed. This mechanism provides a way to examine “stall torque”, delivered by automatic transmissions when the vehicle takes off. Typical dynamometers without this mechanism can not simulate complete zero wheel speed due to heat and control issues.

### DC Power Supply / Virtual Battery (③⑤)

In powertrain system testing for HV/EV, a power supply for the E-Motor is required. When a battery is used as the power supply, it is necessary for the battery to have consistent characteristics, such as charging/discharging, in order to ensure repeatability. However, battery output varies depending on ambient temperature, state of charge (SOC), deterioration and etc. Also, the possibility of the SOC exceeding the upper limit or the lower limit of actual batteries must be taken into consideration, which could restrict test patterns. Due to these factors, a control system (Virtual Battery) is integrated in this system as a power supply for the E-Motor, which controls DC power supply based on a “battery model”. Virtual Battery can simulate the performance of several kinds of batteries by utilizing dedicated software. Before testing, customers can choose one of several typical battery pre-installed models or simulate their own battery’s performance by entering custom parameters. Compared to when a real battery is used, improvements on test efficiency, repeatability and reliability are expected, potentially contributing to simultaneous and dynamic development of battery and energy system.

The DC power supply is capable of supplying 200kW, which compares the output of a typical passenger car. The DC power supply is installed in the same power cabinet used for operating the dynamometers. The improvement in regeneration ratio reduces power consumption. Safety is also considered by using dedicated DC Power interface box with special inter-lock system.

### Automation System (④)

Evaluation of transmissions and E-Motors in this system is controlled by an automation system (HORIBA STARS). STARS implements many automatic test functions such as Work Flow, Test Schedule, calculation functions and scripts that customer can program. STARS also provides interfaces to communicate with over 100 types of measurement equipments including electrical power measurement and ECU data reading/writing. This enables the system to perform a various kinds of tests. In automatic transmission and CVT testing, STARS can also send various types of information from Virtual Engine to Transmission ECU by using STARS calculation function.

### LLC · ATF Temperature Conditioning Unit (⑥)

The LLC · ATF temperature conditioning unit is a system that controls the temperature of Long Life Coolant (LLC) and Automatic Transmission Fluid (ATF). Stabilizing the temperature condition of the transmission, E-Motor and inverter improves test efficiency, repeatability and reliability of the data acquired. When testing an E-Motor, the option to use the pump either in the conditioning unit or in test specimen is available to meet the specification. Liquid-level control is also integrated to be capable of handling any kind of test specimen and test mode.

### E-Motor Mounting Frame (⑦)

Maximum rotation speed of E-Motors is normally twice as fast, or even faster, compared to that of engine. For such high speed operation, resonance of the frame that E-Motor is mounted has to be considered. The E-Motor mounting frame in this system (Figure 7) is designed

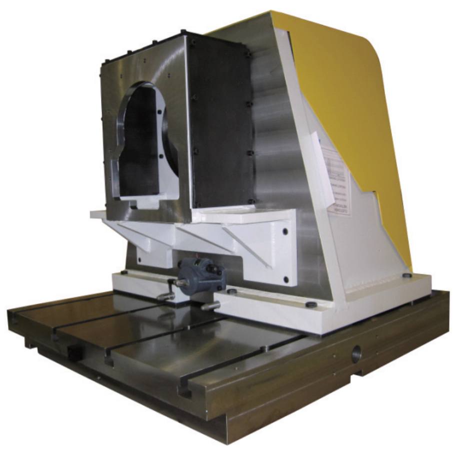

Figure 7 E-Motor Mounting Frame

using CAE optimization so that the natural frequency is higher than the maximum rotation speed to avoid risking resonance.

### Layout Capability

As previously mentioned, this system can be utilized for various kinds of tests for E-Motors and driveline components. However, it is may be necessary to change the layout, depending on the test specimen. In order to reduce the time to arrange components of the system for the test specimen installation, this system has the following positioning mechanisms (Figure 8).

- Virtual Engine and E-Motor dynamometer:
  Longitudinal positioning mechanism①,
  Rotational mechanism②,
  Vertical positioning mechanism③
- Wheel dynamometer:
  Longitudinal positioning mechanism④,
  Alignment adjustment mechanism⑤
- E-Motor mounting frame:
  Longitudinal positioning mechanism⑥

### Simulation Function

#### Engine Simulation

Engine simulation functions, implemented in this system, will be introduced below. These functions are necessary when driveline testing is performed with Virtual Engine.

#### Engine Torque Map Simulation (EMS)

In real engines, output torque is determined by throttle angle and speed. Therefore, output torque is not constant even if throttle angle remains constant. However, the output torque changes depending on engine speed. Engine Torque Map Simulation is a function to simulate the relation between throttle, speed and torque. It enables precise evaluation of acceleration or deceleration on each gear.

#### Engine Inertia Simulation (EIS)

When rotation speeds change due to events such as a gear shift, the inertia torque causes shifting shock, which affects the evaluation results. In this system, Engine Inertia Simulation, which compensates for real engine inertia using electric inertia, simulates the torque response when the real engine speed is changing.

#### Engine Control Signal Simulation (ECS)

In evaluation testing of the transmission with real engines, numerous signals are transmitted and received between engine controller and transmission controller. In this system, the Engine Control Signal Simulation function is utilized to simulate the data communication in a virtual environment. It is possible to simulate shift shock by simulating signals such as torque damping, fuel cut and TDC (Top Dead Center) between the controllers during a gear shift.

#### Engine Torque Pulse Simulation (ETPS)

For reliability tests of gears in transmissions and evaluation tests of parts that undergo torsional vibration, it is necessary to evaluate torque fluctuation caused by engine combustion. In this system, the Engine Torque Pulse Simulation function is utilized to evaluate these effects. A simulated wave form of a 4 cylinder gasoline engine is shown in Figure 9. A theoretically calculated combustion wave form is shown in red, and the actual combustion wave form on the test bed is shown in yellow. By utilizing this function, reliability and vibration can be

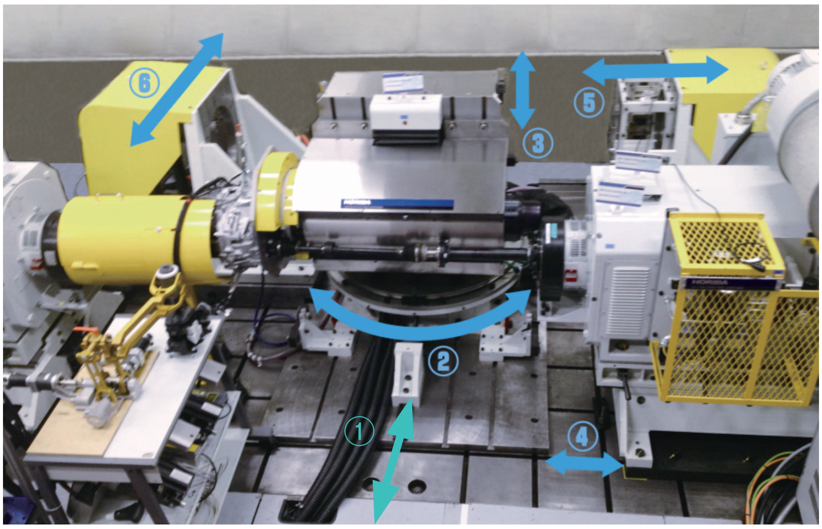

Figure 8 Positioning Mechanism of Dynamometer and Frame

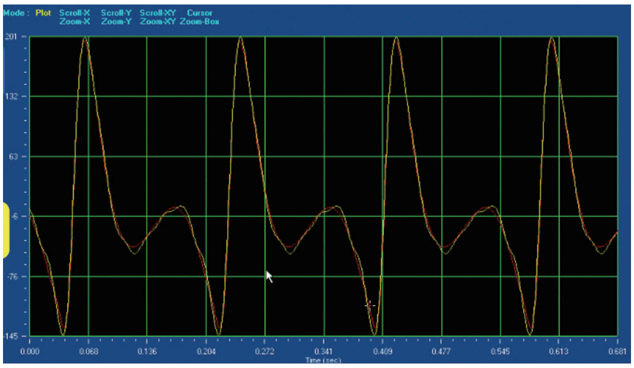

Figure 9 Simulated Wave Form by ETPS (4 cylinder gasoline engine)

evaluated in conditions similar to actual vehicle.

Linkage between Hardware in the Loop System and evaluation system

Nowadays, Vehicle Model Based Development is recommended, and design is generally validated by using simulation. However, there is an outstanding consistency issue between vehicle models used for validation and models used in driveline test systems. To solve this issue, this system performs simulation model on any Hardware in the Loop System (HILS) environments and real time vehicle simulation is performed. Furthermore, the simulation and driveline test system are connected by using high speed synchronized communication, making it possible to link together. The high-speed synchronized communication can be applied to typical HILS hardware available on the market, communicating stably without any delay. The existing HILS hardware and simulation models that run on them can be effectively utilized.

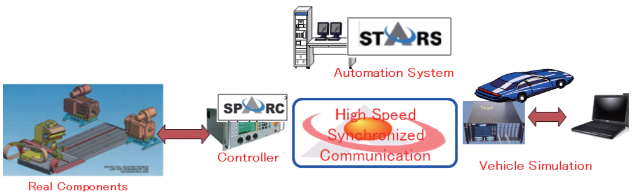

Figure 10 High Speed Synchronized Communication Image with HILS

## Conclusion

In this paper, features and functions of HORIBA driveline test systems installed in Kyoto headquarters were introduced. It is assured that specifications of this system can contribute to customers by improving development efficiency and reducing test duration. Considering the recent expansion of the automotive industry in China, the same test system has been introduced in HORIBA, Shanghai. The laboratory in HORIBA Shanghai plans to confirm its correlation with Kyoto. In order to expand applications to meet market demands closely, HORIBA will continuously create functions and test procedures in response to customer requirements through this test system. HORIBA will enhance its proposal capability for the customers in Japan and China as well as for global customers.

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