Feature Article

Engine Testing

Shigeru Tominaga

Engine testing involves measurement of rotating speed and torque of the engine by applying load controlled by a dynamometer connected to its output shaft. HORIBA has developed various types of dynamometer for the purpose of engine testing. They are mainly classified into two types; one is absorbing only dynamometer such as hydraulic dynamometers and eddy-current dynamometers, the other is absorbing and driving machines such as AC, and DC dynamometers and oil hydraulic dynamometers. HORIBA's DYNAS3 dynamometers, based on AC synchronous and asynchronous motor technology, is the latest model range and has grown into one of the world's leading engine test dynamometer series. HORIBA's solutions for engine testing cover a wide range of applications such as the standard TITAN engine test bench systems, containerized test system, tilt & turn rigs, turbine engine test bench as well as their component parts such as dynamometers, the STARS test automation system and the SPARC real-time digital controller.

Introduction

There is a wide variety of requirements for the test of a vehicle's combustion engine ranging from emissions and fuel economy, durability, noise and vibration optimization in addition to the high performance and responsiveness for acceleration/deceleration. Some of these targets often work against each other: a large number of engine control parameters need to be set to ensure that the engine performance is optimal in consideration of the overall balance between each performance target. Therefore, the development of vehicle can not be realized without engine testing. Engines are designed to be integrated and operated in a vehicle - therefore there are a number of specialist systems and control systems required to run the test engine in isolation. Here is an overview of the components indispensable for engine testing such as dynamometers and also some engine test application examples.

Overview of Engine Testing

Measurement of Engine Torque and Speed

A dynamometer is designed to control engine speed and torque through the process of converting rotating mechanical energy from loaded output shaft of the test engine into electrical or thermal energy. Engine power is calculated from the product of rotating speed and the braking or driving torque seen by the dynamometer. For the measurement of the engine's mechanical parasitic losses or for the simulation of road load dynamics, dynamometers should not only be able to absorb the engine's power output but also to drive the engine.

Figure 1 shows a diagram of a typical torque measuring method. The shaft torque is measured via a strain gauge type load cell which is supported by a lever arm fixed on the dynamometer's pendulum stator. The shaft torque is measured via the strain gauge torque flange mounted on the shaft between the engine and dynamometer.
The speed is measured via a pulse encoder mounted on the dynamometer.

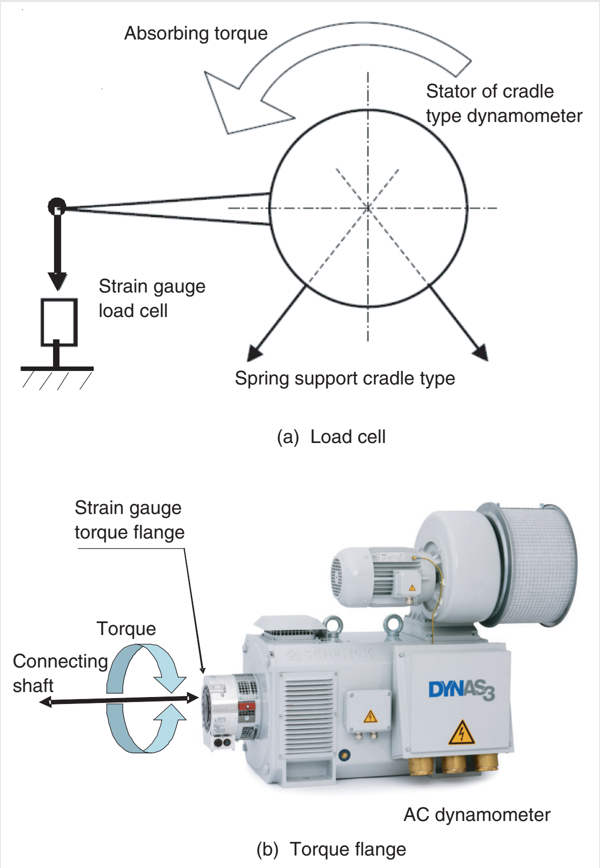

Figure 1 Torque Measurement in Dynamometer

Engine Performance Test and Automation

Figure 2 shows an example of an engine torque characteristic curve, which is created from measurement of the engine's torque generated at different speeds using a dynamometer. The process of engine development requires data acquired at many measuring points in various conditions to establish the engine's characteristics. Sufficient time should be given to each test condition in order that the measurement is made when the engine has reached a thermally stable state; this leads to an extensive period only for data collection. This has driven the development and improvement of automation systems that control test conditions and record key data. Normally automation system can measure, collect and record emission gas component concentrations, fuel economy, temperature, pressure and other measurement items. It also allows operation in prescribed modes required by emission gas measurement legislation and fuel economy measurement.

Recently, electronic control unit (ECU) optimization programs are widely used for engine control. These additionally require significant amounts of test time to create the ECU control characteristic map. This process is the trigger for the development of an automatic mapping tool for ECU optimization.

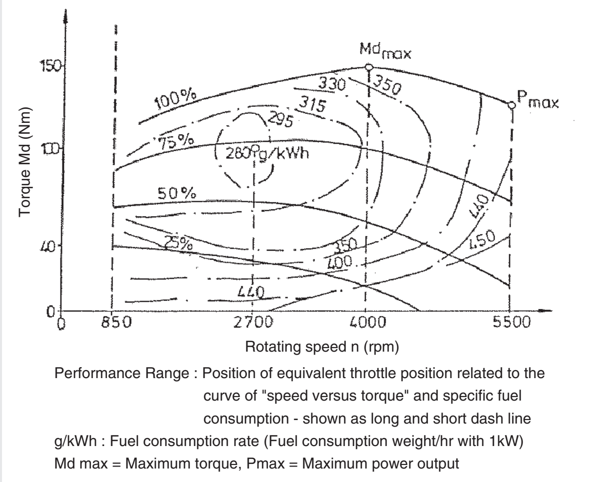

Figure 2 Torque Performance Curve

Simulation Test

Vehicles equipped with ECUs are controlled and operated optimally through the interaction of the engine, transmission, vehicle dynamics, braking system, etc. This interaction creates the requirement to simulate the operation of missing components of the vehicle when a test is performed on items such as the engine or the transmission on a test stand. In response to these needs, engine test benches equipped with driving and absorbing dynamometers and simulation system have been developed.

From HORIBA's wide range of engine test systems we offer DYNAS3 as the driving and absorbing AC dynamometer, STARS as the automation software and SPARC as the real-time digital controller running simulations including driver behavior, driveline components and vehicle characteristics. The driveline simulation supports both manual and automatic transmissions. Tandem dynamometers, the combination of a DYNAS3 and an absorbing type dynamometer, is used for high power engine testing. In addition to the built-in HORIBA simulation model, other third party or customer developed HIL models[*1)] can be integrated into the system to extend the application range.

*1 : HIL stands for hardware-in-the-loop and indicates that a real piece of hardware is testing in a simulated environment. I.e. When an ECU is the target of a development, testing occurs with the real ECU in combination with simulated components such as the engine and driveline. HIL is mainly used in the development test stage of each vehicle component.

Engine Test System

HORIBA's product line of the components for engine test system is outlined below;

Hydraulic Dynamometer

Hydraulic Dynamometers convert the load generated through the rotor movement into heat via the shearing of water between two loss plates. It is an absorbing type dynamometer which can absorb only the torque generated by the engine. HORIBA's DT Hydraulic Dynamometers (Figure 3) are equipped with one or two rotors and control torque through water level regulated by opening an outlet valve. The features of this type of dynamometer are quicker response, better controllability and higher durability than conventional type of hydraulic dynamometers.

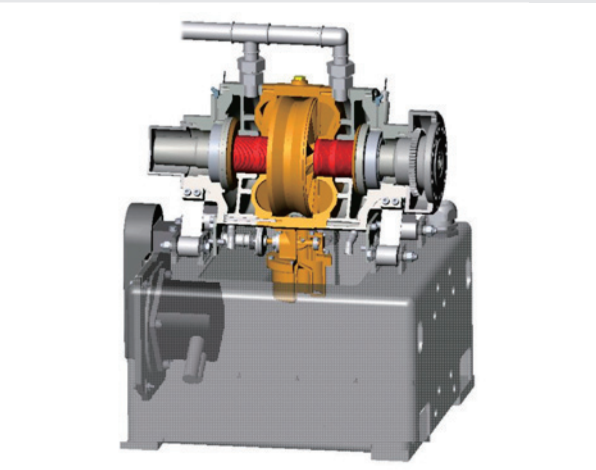

Figure 3 DT Hydraulic Dynamometer (Single Rotor)

Eddy-current Dynamometer

Eddy-current dynamometers are an absorbing type dynamometer which converts internally generating eddy current energy into heat. WT Eddy-current dynamometers (Figure 4) consist of a disc-type rotor and stator, which are constructed in a way that are supported by bearings set outside of cooling chambers. This technology, patented by the former Schenck company, was the origin of the disc type eddy-current dynamometers which are used worldwide nowadays. The dynamometers are suitable for operation in both directions of rotation with a wide range of power absorption and control. Due to its ability to cover a the wide range of applications from steady state to transient test stands, it is used not only in the engine development stage but also in various engine assembly lines.

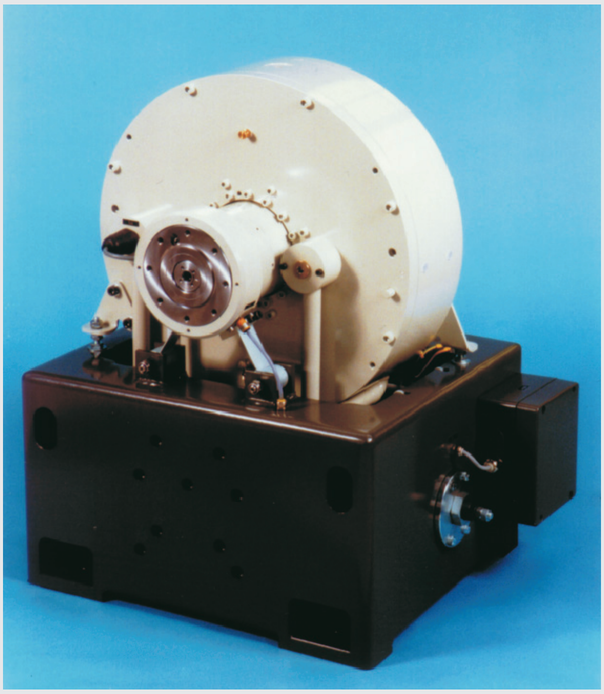

Figure 4 WT Eddy-Current Dynamometer

AC Dynamometer

A driving and absorbing type of dynamometer is used for a wide range of applications from simple steady state test to transient tests and simulation of the vehicle's road loads. HORIBA has developed ranges of DC dynamometers, oil hydraulic dynamometers and AC dynamometers. HORIBA's latest dynamometer range DYNAS3 (Figure 5), based on AC motors, is the 4th generation of their electrical machine dynamometers. After a number of evolutions, $DYNAS_3$ has become the leading dynamometer in its class.

DYNAS3 is integrated with a torque measurement flange and optical pulse encoder which can achieve the highly dynamic and accurate control required for modern testing. The DYNAS3 series has an extensive range of models for use in engine development and engine production all with excellent torque response and high power range. The dynamometers are controlled using state-of-the-art power inverters and drives. These drives with their integrated power filters can generate power back into the plants mains supply very efficiently and therefore can reduce the overall site electrical power consumption.

Figure 5 AC Machine, DYNAS3

Tandem Dynamometer

Tandem Dynamometers (Figure 6) are the combination of an absorbing type of dynamometer such as a hydraulic dynamometer or eddy-current dynamometer and an electrical machine dynamometer such as an AC dynamometer. With their large absorbing power, Tandems characteristics include lower inertia, high speed and high torque. Consequently, they are suitable for heavy duty engine testing for engines larger than 500kW.

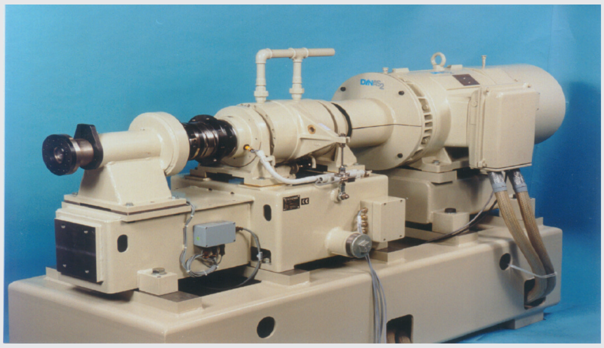

Figure 6 Tandem Dynamometer

Control System

Automation System

Originally engine automation system simply transmitted the demand values for torque, speed and throttle position on a time basis - today automation systems have become much more capable and complex. HORIBA's latest generation test automation system STARS provides a complete test environment from data management to sophisticated simulation. STARS is a multi-purpose system with many functions integrated in a highly flexible environment. The main features are as follows;

- A single test system that can capture an entire testing process for a wide range of applications from engine and component testing, driveline testing, brake testing and vehicle testing.
- User friendly interface with a familiar Windows-OS environment and real-time software
- Powerful real-time test schedule running up to 1kHz and an easy link with the SPARC digital controller (as described below) running at 1kHz
- Visual display of the test using STARS workflows and easy test running via icons.
- Multi-level limit alarms and multiple data loggers running up to 1kHz
- Road Load Simulation, which simulates vehicle road testing on an engine test stand

Real-time Digital Controller

SPARC, a real-time digital controller (Figure 7), was developed for not only engine testing applications but also for the same wide range of applications as STARS. In addition to manual stand-alone operation, SPARC can be integrated with STARS or can be connected with third-party automation systems. It is equipped with on-board 5kHz analog, digital and pulse input and output to ensure accuracy in data acquisition and control. Six built-in CAN bus ports provide an expandable interface. SPARC employs highly repeatable control algorithms specially designed for engine and driveline testing. Advanced technology such as engine mapping can be integrated into SPARC to realize more accurate and higher speed engine control.

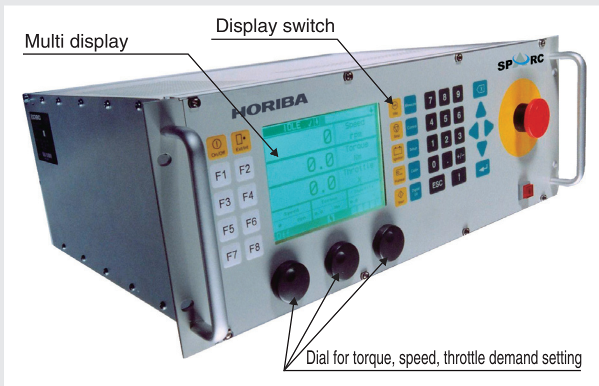

Figure 7 Real-Time Digital Controller SPARC

Application for Engine Test System

Standard Engine Test System

The DYNAS$_3$ AC dynamometer, SPARC and STARS test automation system are combined together with electrical and mechanical engine test components and data acquisition to realize HORIBA's latest generation engine test system. HORIBA offers the TITAN series as standard engine test systems, which also include peripheral devices and modules such as engine cooling systems that can be mounted on the basic engine test system (Figure 8). The TITAN systems are configured either as complete standard systems or as from a series of standard modules that can be combined to create a system specifically to meet customers' exact requirements.

Figure 8 Standard Engine Test System, TITAN

Containerized Test System

Containerized test systems are available from HORIBA and are composed of a container that accommodates a complete engine test system (Figure 9). One of the biggest features is that it allows the test system to be installed and commissioned in a short period of time because all the necessary components are already installed and proven in the container. It can be installed outdoors as well as indoors and can be relocated easily after having been installed once. These features give the system the flexibility meet the needs for the extension or conversion of an existing test field.

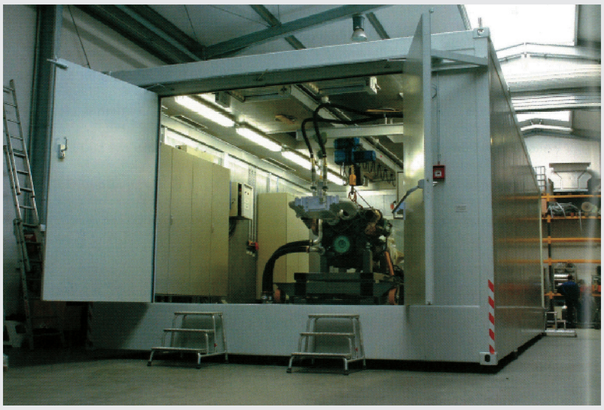

Figure 9 Containerized Test System

Tilt & Turn Test System

A Tilt & Turn test bench is used to simulate road slope and acceleration (Figure 10). Dynamometer, engine and peripheral equipment are installed on the engine bench assembly which can all tilt and turn at angles in a range up to 55 degrees. The impact this tilt has on lubrication systems such as the oil pan, oil pump, foaming map and oil spray and engine function in the tilted and/or turned state can be examined using the system.

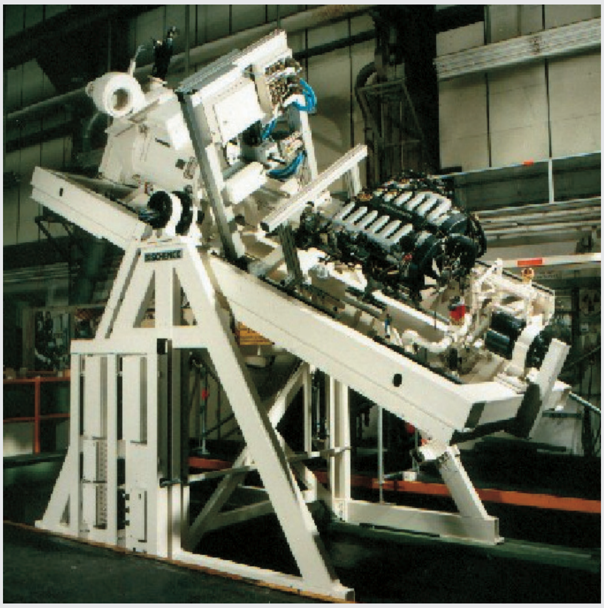

Figure 10 Tilt & Turn Test System (AC dynamometer installed with a V12 engine connected)

Gas Turbine Test System

The tests of gas turbines used for electric power plants and aircraft require test systems that deliver low inertia and high performance to respond to the transient load of the engine together with highly accurate measurement with good reproducibility. For many years, HORIBA has supplied dynamometers, control and measuring equipment and automation systems for shaft turbine engine test systems. Gas turbine test system (Figure 11) allows measurement of power/speed/torque, gas turbine testing, development of turbine technology, running-in, endurance running, etc.

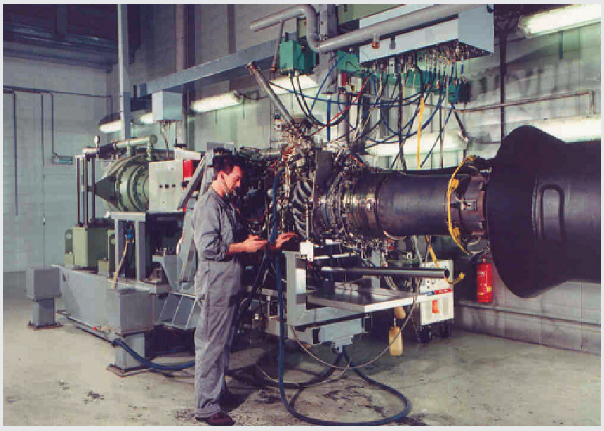

Figure 11 Gas Turbine Test System (Hydraulic Dynamometer D)

Conclusion

For many years HORIBA has offered a variety of engine test systems containing market leading test products and components. Our engine test system mission is to develop products that meet the demands of today's worldwide markets as well as satisfying future needs. Last, but by no means least, we aim to be the world's most reliable provider of engine test solutions offering advanced user-friendly products and also taking full advantage of our proven, accumulated experience and know-how.

Shigeru Tominaga
HORIBA, Ltd.
Automotive Test Systems Division
Automotive Mechatronics Dept.