Performance Test System Reproduces the Usage Environment of EV Drive Components

OTAKE, Katsutomo*　MIHARU, Tsutomu*　MIYAMOTO, Hiroyoshi*

ABSTRACT

The electrification of automobiles has been progressing rapidly today in the face of global emissions regulations and decarbonization. As electric vehicles (EVs) especially use complex control, the labor-hours for testing can significantly increase to develop them and demand has been increasing for EV test equipment. In response to this demand, Fuji Electric has developed an EV drive component performance test system. The system can simulate the load during actual road driving and actual environmental testing factors of temperature and humidity to improve test efficiency and reliability.

1. Introduction

In the automotive industry, electrification has been progressing rapidly in the face of global emissions regulations and decarbonization, and it is estimated that approximately 55% of the vehicles sold in Japan in fiscal 2030 will be electric vehicles (EVs)[1]. Unlike gasoline-powered or diesel-powered vehicles, EVs use complex control. For this reason, the labor hours required to test them may be significantly higher, and demand has been increasing for EV test equipment to improve reliability and test efficiency.

In response to this demand, Fuji Electric has developed an EV drive component performance test system.

This paper describes a performance test system that reproduces the usage environment of EV drive components.

2. Overview of the EV Drive Component Performance Test System

The EV drive component performance test system consists of an EV drive component performance tester, a thermostatic chamber, and a temperature controller. This system can reproducing realistic driving environments to test EV drive components, such as motors, inverters, and decelerators.

Figure 1 shows the EV drive component performance test system.

In order to reduce their size and weight, progress is being made in the rotation speed of EV motors, with the maximum speed reaching 20,000 r/min. In addition, the thermal environment of in-vehicle parts has become extreme due to the high-speed rotation and dense concentration of EV motors, inverters, and electronic parts. Therefore, it is necessary to evaluate whether any problems in performance and reliability arise under extreme temperature environments.

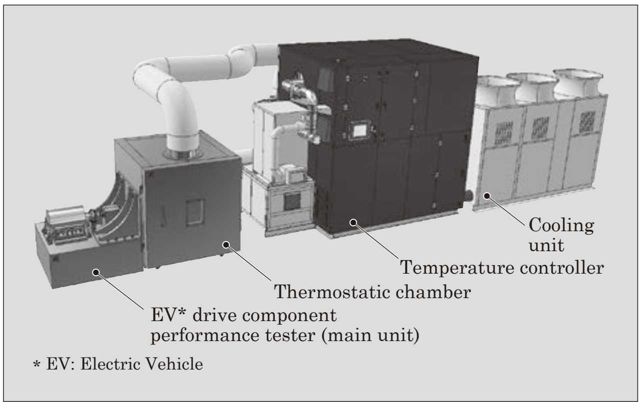

Fig.1 EV drive component performance test system

2.1 EV drive component performance tester

The EV drive component performance tester is designed to evaluate a single specimen, simulating the load in actual road driving conditions. This tester is composed of a dynamometer for generating a load on the specimen and reproducing load states such as driving conditions, a torque meter for measuring the rotational force applied to the shaft between the dynamometer and the drive components, an intermediate bearing for supporting and reducing the load applied to the dynamometer and the drive components, an angle plate for attaching an EV motor, and a rack for assembling these parts. Figure 2 shows the EV drive component performance tester (main unit).

For EV motors, high-speed rotation is indispensable for achieving both size and weight reduction, as

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

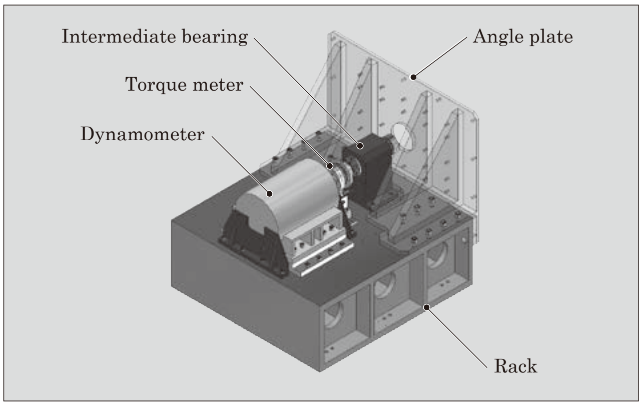

Fig.2 EV drive component performance tester (main unit)

well as high power. It is necessary to deal with specific problems caused by high-speed rotation in the test equipment. A high-speed rotating system requires the characteristic vibrations of the system to be detuned according to the rotation speed of the specimen to suppress the generation of resonance, as well as a cooling system and auxiliary equipment for lubrication due to the rise in temperature in the system caused by high-speed operation. For these reasons, the mechanical configuration becomes complex, resulting in more mechanical challenges than electrical challenges.

2.2 Thermostatic chamber and temperature controller

The thermostatic chamber and temperature controller are for reproducing the usage environment, including temperature and humidity in the thermostatic chamber. This system comprises a temperature controller for controlling temperature and humidity in the thermostatic chamber, a cooling unit for supplying refrigerant to a cooler in the temperature controller, a humidifier for supplying moisture, and other components. Figure 3 shows a diagram of the thermostatic chamber and temperature controller configuration.

In electric vehicles, the amount of heat generated by electronic parts has increased due to the reduced size and increase in capacity of motors, inverters, batteries, and other components, as well as the integration of these components in limited spaces. The increase in the amount of heat generated by electronic parts may decrease their performance or shorten their life. Automakers and auto parts suppliers are increasingly required to evaluate the reliability of electronic parts from the viewpoint of safety and security and must verify quality through rigorous testing in various realistic simulated driving environments. However, small-capacity products for evaluating small parts are common for environmental test equipment, while large-capacity equipment for evaluating medium- and large-sized auto parts in the driven state is rare. In addition, equipment that simulates the temperature environment while absorbing the exothermic load fluctuation of the unit is expensive because they are one-off products, rather than general-purpose product. For this reason, many of this type have not been introduced in the market. Therefore, evaluation tests are often conducted in a natural progression according to a cold or hot start.

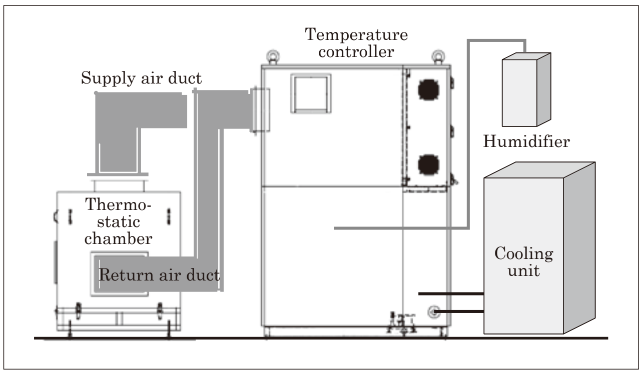

Fig.3 Thermostatic chamber and temperature controller configuration diagram

3. EV Drive Component Performance Tester Features

3.1 Challenges

In the high-speed rotation tests, the resonance may cause sudden wear and tear of the bearing and increase the swing of the rotating shaft system, leading to failure. To avoid machine breakage, it is necessary to separate the characteristic vibrations from the rotational frequency of the test equipment. As a countermeasure, it is effective to increase the rigidity and reduce the weight of the EV drive component performance tester. In addition, to reduce centrifugal force, the design must take into account the dynamic balance adjustment of the rotating shaft.

As the increase in energy in high-speed rotation tests results in a large amount of generated heat, flaking failure may occur due to bearing seizure caused by poor lubrication. Therefore, oil is commonly used to lubricate and cool the bearing simultaneously. However, when oil lubrication is used, the machine configuration must include an oil pump and a heat exchanger, leading to increased complexity. Furthermore, the surrounding area becomes contaminated by oil mist, and as a result, the scope of equipment maintenance expands. For this reason, many users have asked to avoid the use of oil lubrication if possible.

3.2 Countermeasures and effects

When developing highly-reliable, high-speed rotating test equipment, it is necessary to predict the characteristic vibrations of the equipment at the design stage to ensure suitable rigidity of the structure. We set the vibration frequency to 333 Hz (20,000 r/min) at the driving rotational speed and the detuning rate* to

* Detuning rate: Separation rate with respect to the rated speed of the resonant speed

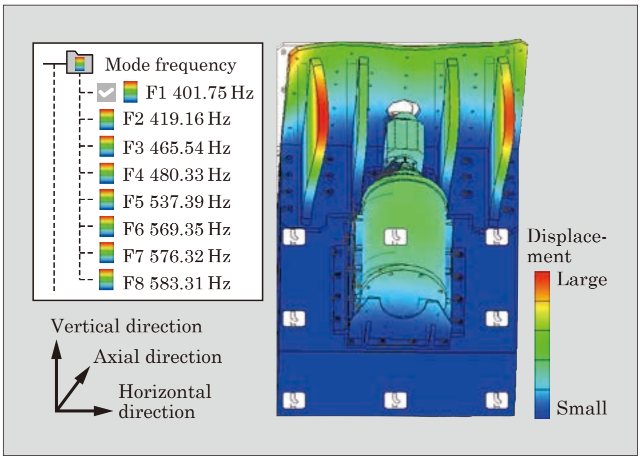

Fig.4 Vibration modes of the EV drive component performance tester and primary characteristic vibration analysis results

approximately 20% as the design value. In the design of the test equipment, we conducted vibration analysis using the finite element method and obtained characteristic vibrations. Based on the analysis results, we adjusted the beam and thickness to optimize the structure by balancing the high rigidity and light weight of the equipment.

Figure 4 shows the vibration modes of the EV drive component performance tester and the primary characteristic vibration analysis results.

As a result of structural optimization, the characteristic vibrations of the primary vibration mode was 401.75 Hz, and a detuning rate of 20.4% was ensured against the rotational frequency vibrations (333 Hz).

In addition, we measured the vibrations by actually operating the equipment to confirm the validity for the resonance examination. In the measurement, we evaluated the intermediate bearing, which is most likely to generate vibrations because it supports the weight of the rotating body, and the rack, which is affected by vibrations from the whole rotating system. With regard to the evaluation criterion for vibration measurement, the limit value for vibration speed was set to 2.8 mm/s or less in accordance with JIS B 0906 to determine whether the measured vibration value was a normal value or an abnormal value.

Table 1 shows the measurement results of the vibration level of the EV drive component performance tester. The vibration speed of 2.8 mm/s or less was cleared at all measurement points, and the desired vibration level was achieved under high-speed rotation.

The intermediate bearing uses grease lubrication instead of oil lubrication. The advantage of grease lubrication is that it does not require disassembly work for the equipment piping or other components, nor does it require internal oil treatment work. Instead, only the simple task of greasing is required for maintenance. Although grease lubrication means good maintainability, the cooling efficiency is lower than that of oil lubrication, so care must be taken to prevent seizures caused by temperature rise.

Table 1 Measurement results of the vibration level of the EV drive component performance tester

Subject	Intermediate bearing					
Measuring point	Specimen side			Dynamometer side		
Vibration direction	Axial	Horizontal	Vertical	Axial	Horizontal	Vertical
Vibration speed (mm/s)	1.87	1.82	0.01	0.01	2.52	1.99
Subject	Rack					
Measuring point	Specimen side			Dynamometer side		
Vibration direction	Axial	Horizontal	Vertical	Axial	Horizontal	Vertical
Vibration speed (mm/s)	0.30	0.43	0.26	0.27	0.48	0.25

Table 2 Intermediate bearing temperature measurement results

	Dynamometer rotational speed (r/min)
	20,000
Specimen side temperature (°C)	60
Dynamometer side temperature (°C)	57

In this design, we set the upper limit temperature of the bearing to 120°C or less and examined the following three points as key considerations for suppressing temperature rise in the intermediate bearing by reducing the vibration of the bearing, improving the rotation accuracy, and properly lubricating the bearing.

(1) Examination of the suppression of centrifugal force

We determined the balance grade to reduce to a target value the spherical surface pressure of the bearing due to centrifugal force.

(2) Selecting pressurization that takes into account rotation accuracy and lubrication

Axial-direction constant surface pressure is designed to be applied to the bearing in spite of against temperature changes.

(3) Selecting a lubricant agent

We selected urea grease for its heat resistance.

To confirm the validity of this design, we measured the temperature of the intermediate bearing.

Table 2 shows the intermediate bearing temperature measurement results. The results of the temperature measurements were within the upper limit of use.

4. Temperature Controller Features

4.1 Challenges

Automotive tests include soaking operation and mode tests. As soaking operations stop until the specimen reaches the test temperature, no heating load is involved, and the cooling unit stops due to the light load. The stopped cooling unit cannot provide constant cooling performance or maintain stable temperatures because it restarts after a restart prevention delay time has elapsed. On the other hand, in the mode test, the heating load fluctuates greatly between 0% and 100%, and the equipment must be optimally controlled to track the temperature according to the fluctuations.

We consider these problems to be challenges to tackle in the process of achieving the following targets in equipment development.

(a) Temperature tracking performance within ±1°C with respect to thermal load fluctuation
(b) Construction of an environment that enables continuous operation even in low temperature environments
(c) Minimization of installation area, ancillary work, and adjustment time

The conventional method of constructing an automobile test environment is to combine heat source equipment that produce normal temperatures, low temperatures, and high temperatures at the test site. In this development project, we have integrated and optimized heat source equipment of all temperature ranges as a means of addressing these challenges.

4.2 Countermeasures and effects

To achieve a temperature tracking performance within ±1°C with respect to heat load fluctuations, it is necessary to prevent stoppage and hunting of the cooling unit to ensure stable operation regardless of the state of heat load fluctuations. Figure 5 shows the configuration of a temperature controller configuration.

(a) As a countermeasure against light load stoppage of the cooling unit during soaking operations, heat is output from electric heater (a) installed on the primary side of evaporator (a), and the heat load is applied to evaporator (a) to continue operation of the cooling unit, as shown in Fig. 5. On the other hand, in the mode test, the refrigerant flow rate is controlled by expansion valve (a), and the evaporation pressure is controlled by evaporation pressure regulating valve (a) according to the exothermic load fluctuations of the specimen. In addition, we found the optimum value of the variable PID control of the electric heater before and after evaporator (a), while simultaneously ensuring the continued operation of the cooling unit.
(b) Using the return refrigerant piping at the outlet of the dehumidifier system that was integrated with the cooling unit system, a suction injection circuit is formed. As a result, the intake piping gas temperature of the compressor is kept within the specified value, and continuous operation of the cooling unit is ensured even under light load with an elevated temperature setting. Figure 6 shows the cooling circuits.
(c) Deviating from the practice of using different cooling units selected from the viewpoint of efficiency for evaporators of different temperature zones and using low-temperature cooling units to achieve –40°C, we adopted a cooling unit that can respond to large load fluctuations. While the refrigerant of conventional equipment is R404A (boiling point of –46.1°C), the refrigerant in the newly developed equipment is R410A (boiling point of –51.4°C). Figure 7 shows the capacity control of the cooling unit for the conventional equipment as compared to the newly developed cooling unit. The conventional equipment consists of a medium-temperature inverter and a cryogenic constant-speed machine, but the newly developed equipment uses an inverter that can cover the entire temperature range, enabling stable capacity control against load fluctuations.

Figure 8 shows the load tracking performance during the mode test. As shown in Fig. 8, as a result of the measures in (a) and (b), a highly accurate load tracker with an air supply temperature in the range of –40±1°C has been achieved, even when the load fluc-

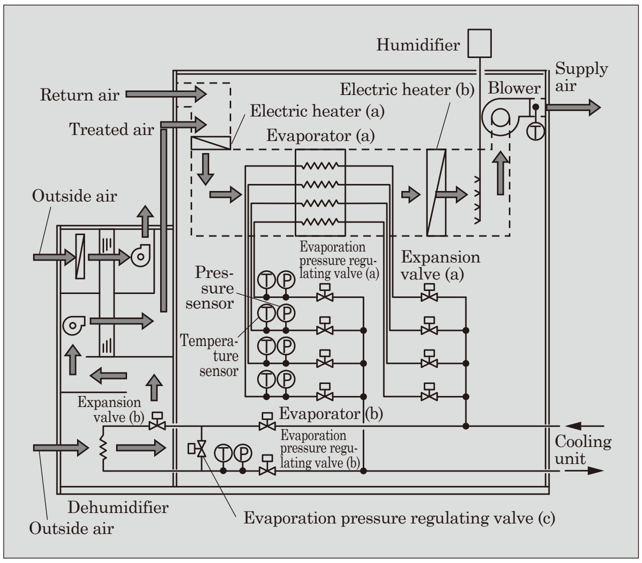

Fig.5 Temperature controller configuration diagram

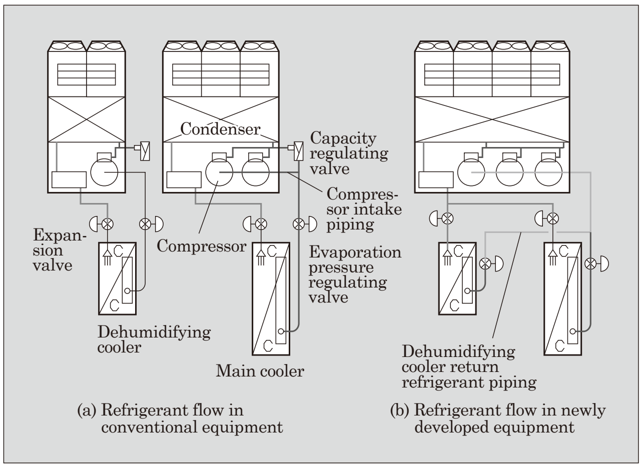

Fig.6 Cooling circuits

issue: Instrumentation, Control, and Information Systems Contributing to Automation and Energy Saving

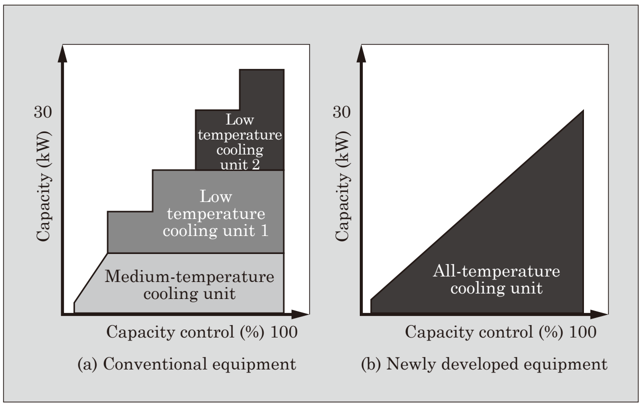

Fig.7 Capacity control of conventional equipment and the newly developed equipment cooling unit

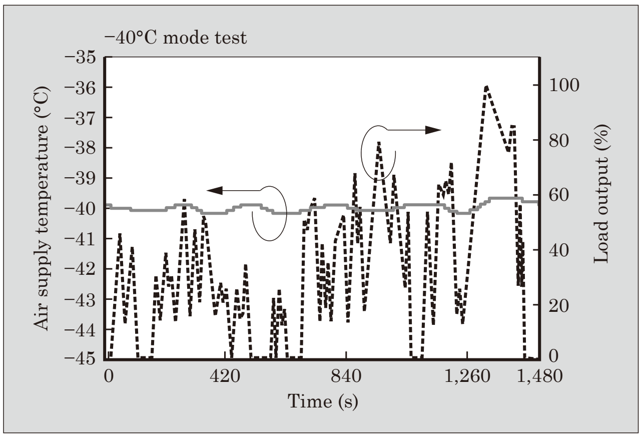

Fig.8 Load tracking performance during mode testing

tuates by 0% to 100% in the low temperature region, which is the most severe condition.

In addition, as a result of the comprehensive optimization and review of components conducted in the process of implementing the measures described (a) to (c), we have completed a small, packaged product. As a key example, the pitch of the heat transfer fin has been narrowed from 8 mm to 6 mm because the introduction of the dehumidifier has prevented frost from forming. Moreover, the frosting coefficient used to take into account the decrease in heat exchange efficiency caused by frost, which had been a consideration in the design of conventional coolers, can be set to 1 (usually, 0.6 to 0.7), resulting in a significant reduction (by approximately 45%) in the volume of the cooler, which affects the device size. In addition, as described above, the cooling unit system has been integrated to reduce the installation area (by approximately 45%).

Table 3 compares the newly developed equipment with conventional equipment.

Table 3 Results of comparison with conventional equipment

Conventional equipment		
Cooler		Cooling unit
Medium temperature cooler 1	14 columns × 20 rows × 830 L	10 HP inverter
Low temperature cooler 2	16 columns × 10 rows × 830 L	20 HP constant-speed machine
Low temperature cooler 3	16 columns × 10 rows × 830 L	20 HP constant-speed machine
Dehumidifying pre-cooler	16 columns × 6 rows × 250 L	5 HP inverter
Total	522 m (1.3 m^3)*1	55 HP (4.3 m^2)*2

Product prototype		
Cooler		Cooling unit
All-temperature cooler	22 columns × 20 rows × 650 L (quadruple split)	40 HP inverter
Dehumidifying pre-cooler	16 columns × 6 rows × 250 L	
Total	310 m (0.7 m^3)*1	40 HP (2.4 m^2)*2

*1 Volume occupied by the effective part of the cooler
*2 Cooling unit installation area

4. Postscript

This paper has described a performance test system that reproduces the actual environmental conditions in which EV drive components are used. Future EV systems are expected to have higher rotational speeds and higher voltages. As such, new technological challenges need to be tackled. Fuji Electric will continue to provide products that contribute to the improvement of test efficiency and reliability in powertrains.

References

(1) Global Car Sales Through 2030 by Powertrain Type, Boston Consulting Group, January 10, 2020, https://www.bcg.com/ja-jp/publications/2020/drive-electric-cars-to-the-tipping-point, (accessed 2023-02-10).

Fuji Electric

Innovating Energy Technology

＊ All brand names and product names in this journal might be trademarks or registered trademarks of their respective companies.