

# Development of Meiden's e-Axle Traction Motor System

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## Abstract

As an electric powertrain whose demand has grown in recent years, e-Axles are attracting attention in the market. An e-Axle is a fully integrated traction motor system that combines the motor, inverter, and gear. The expected benefits are an improved vehicle space and shorter vehicle development period.

We researched the mounting requirements for Electric Vehicles (EVs) and market trends. We recently developed the fully integrated traction motor system called "Meiden's e-Axle". It is characterized by being a top-class compact, light-weight, and high continuous rated output. It combines a high-speed motor and a high gear ratio and adopted a flat winding and self-circulating oil cooling system. By these features, we realized a compact e-Axle product that can be installed even in a narrow space under the rear three-row seat.

In addition, we have also developed an evaluation system for EV powertrains. In this system, we can evaluate axle output and perform driving simulation.

## 1 Preface

e-Axle is a fully integrated traction motor system combining the motor, inverter, and gear (reducer or differential). Such components are required for the traction of Electric Vehicle (EV). In the conventional method, each unit is separately mounted in the EV. We recently developed the integrated traction motor system called "Meiden's e-Axle". By the integration, we realized a compact and light-weight design. It will contribute to the EV car, with more inner space and enhanced energy efficiency. Due to such merits, it is expected that the industry's demand for e-Axle will rapidly increase in the future. In this paper, we will introduce the features and specifications of Meiden's e-Axle. We will also introduce the evaluation system for e-Axle.

## 2 Features

The features of Meiden's e-Axle are as follows.

- (1) The estimated vehicle to be installed is the C segment (medium car – EV's core class)
- (2) By being light-weight and compact, it will be mounted in the EV, and can be applied to various types of EVs (very general purpose) like Front-Wheel Drive (FWD), Rear-Wheel Drive (RWD),

Four-Wheel Drive (4WD) or Plug-in Hybrid Vehicle (PHEV).

(3) The lower center of gravity by lowering the platform floor design. Because of the standard intermediate shaft, torque steering<sup>\*1</sup> (improvement of vehicle motion characteristics) is eliminated.

(4) By achieving high continuous rated output, it improved the performance in the case of climbing slopes or cruising at high-speeds (improvement of practical performance).

(5) We introduced an evaluation system that includes the axle performance. We can eliminate rework in vehicle testing (shorter vehicle development period at the customer)

## 3 Specifications

Table 1 shows the performance and specifications of Meiden's e-Axle. Fig. 1 shows the external dimensions. Fig. 2 shows the trend of motor output for the C segment. We expect our product will be equipped in the C segment EV cars. The C segment is the key segment for the car electrification.

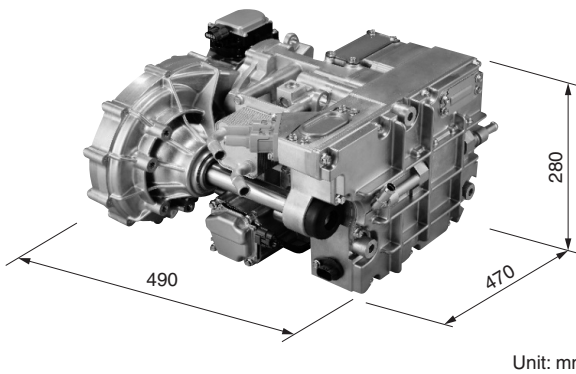
The maximum rated output is 150 kW, set based on recent trends of product offerings by the competition. Continuous rating output was set to 100 kW. In deciding this rate, we valued practicality

**Table 1 Performance and Specifications**

Performance characteristics and specifications of the developed product are shown.

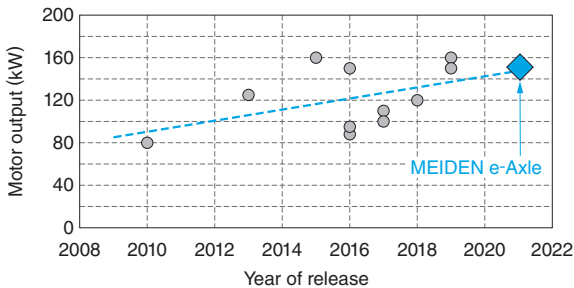
Item	MEIDEN e-Axle
Maximum output <sup>※1</sup>	150 kW
Maximum torque (motor) <sup>※1</sup>	3120 N·m (260)
Continuous rated output	100 kW
Continuous rated torque (motor)	1680 N·m (140)
Max. revolving speed (motor)	1333 min <sup>-1</sup> (16,000)
Reduction gear ratio	12.0
Mass	78 kg
Dimensions	W470 × H280 × L490 mm

Note. ※1. 30 s rating



**Fig. 1 External Dimensions**

Dimensions of the developed product are shown.



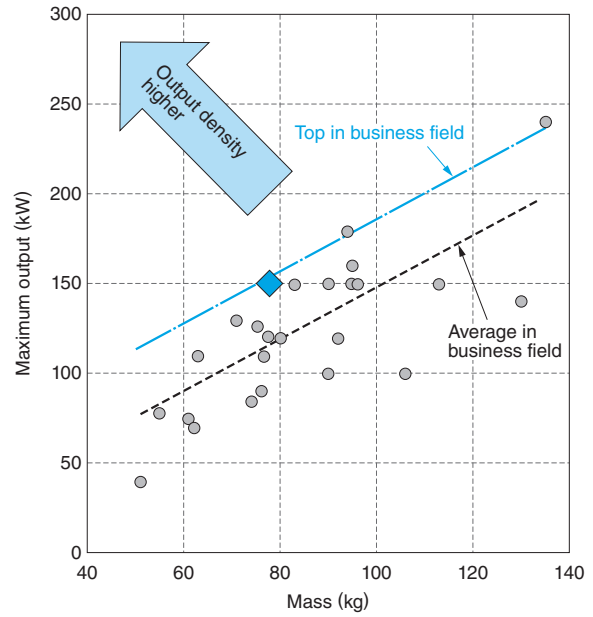
**Fig. 2 Trend of Motor Output for C Segment**

It is understandable that the motor output tends to increase year to year.

and a top-class rating.

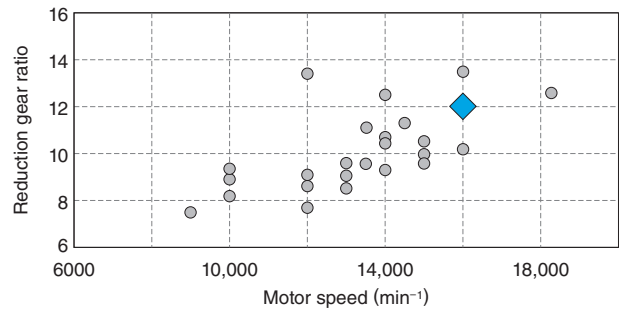
### 3.1 Top Class Compact and Light-Weight Design

Mass reduction is as important as efficiency since it affects the energy efficiency of the EV. Fig. 3 shows the output and mass of each company's e-Axle. The broken line shows the distribution trend of each company's e-Axle, and the dashed



**Fig. 3 Output and Mass of Each Company's e-Axle**

The relationship between mass and output of each company's products is shown. In the top left of the graph, superiority in output density is shown. It is recognized that the output density of Meiden's e-Axle is top class.



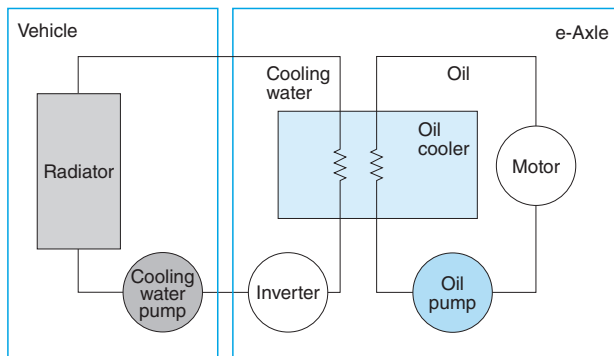
**Fig. 4 Motor Rotation Speed and Reduction Ratio of Each Company's e-Axle**

Motor revolving speed and reduction gear ratio by each company are shown.

line shows the most light-weight model line. This is presumed from the distribution trend.

#### 3.1.1 High Rotation Speed and High Reduction Ratio

Fig. 4 shows the motor rotation speed and reduction ratio of each company's e-Axle. For currently available motors and reduction gears, a combination of 10,000 min<sup>-1</sup> to 12,000 min<sup>-1</sup> and gear ratio being around 10 is most popular. As a result of our study on the aforementioned advantages and issues in realizing more than the competition's level, we decided the motor speed to be 16,000 min<sup>-1</sup> and the gear ratio to be 12.



**Fig. 5 Schematic Diagram of Self-Contained Type Cooling System**

Cooling water supplied from the vehicle is used for heat exchange for the inverter and motor cooling oil. The built-in electric oil pump is used to circulate the cooling oil so that direct cooling is carried out by injecting the oil inside the motor.

**3.1.2 Self-Circulating Oil-Cooled Motor**

A motor compact design has been realized by adopting the oil-cooled method, and a high output of continuous rated output 100 kW is realized. The motor is of the self-circulation oil-cooled type where a cooling-oil circulating system is incorporated inside the motor. This system does not require cooling oil from the vehicle side and it allows more design freedom in designing the vehicle layout.

Fig. 5 shows a schematic diagram of the self-contained type cooling system. Cooling water supplied from the vehicle is used for heat exchange for the inverter and motor cooling oil. The built-in electric oil pump is used to circulate the cooling oil so that direct cooling is carried out by injecting the oil inside the motor.

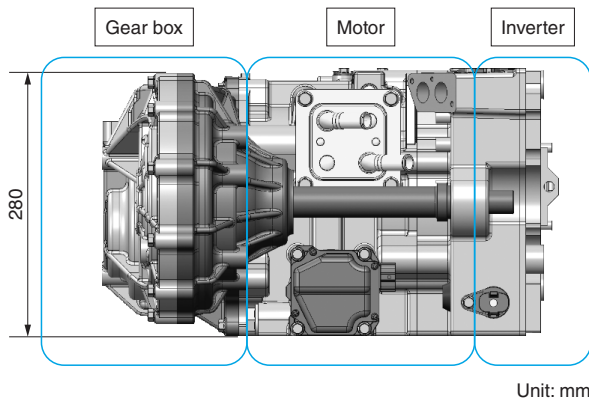
**3.1.3 Mounting at a Low Position Lower Installation Point under the Floor (Low Center of Gravity)**

Fig. 6 shows the layout of each component. By arranging a motor, an inverter, and a gear into the axial direction, we realized the thinnest e-Axle shape in its class (height 280 mm). As a result, we realized a compact e-Axle that can be mounted in a narrow space under the rear three-row seats.

This lowering contributes to better driving stability thanks to the effect of low center of gravity in the vehicle. Fig. 7 shows a mounting image to the vehicle.

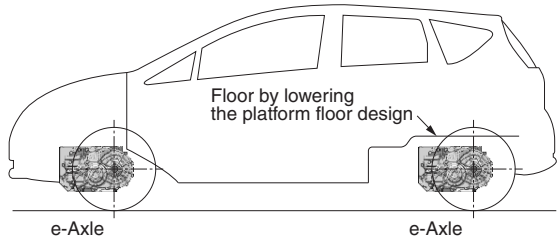
**3.2 High Continuous Rated Output**

Many products in the same class have a continuous rating of 50 to 80 kW. Continuous driving, however, is not possible in the high speed range. It is



**Fig. 6 Layout of Each Component**

Layout configuration of the gear box, motor, and inverter is shown.



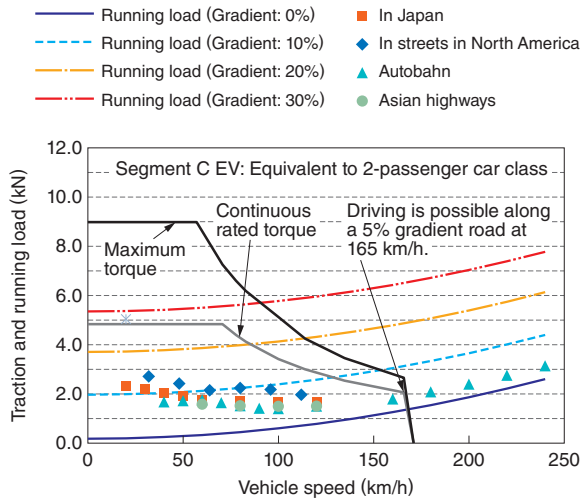
**Fig. 7 Mounting Image to Vehicle**

A side-view mounting image in the vehicle is shown. Since the e-Axle is for lower platform floor design, it can be mounted even on the rear side of a 3-row seat vehicle.

assumed that even around 100 km/h, there may be no allowance in dynamic performance. Considering the practical performance such as climbing slopes and high-speed cruising, we set the continuous rating at 100 kW. Fig. 8 shows the curves of driving torque and the running load. These running load curves are the characteristic curves of maximum torque, continuous rated torque, and gradients. It shows the running load with dots based on street limit speeds regulated all over the world and on the basis of road design standard gradients. The inside (bottom left) of the continuous rated torque curve indicates that continuous running is possible. According to these characteristic curves, it can be said that Meiden's e-Axle is capable of assuring continuous running through any roads in the world at the maximum speed of 165 km/h.

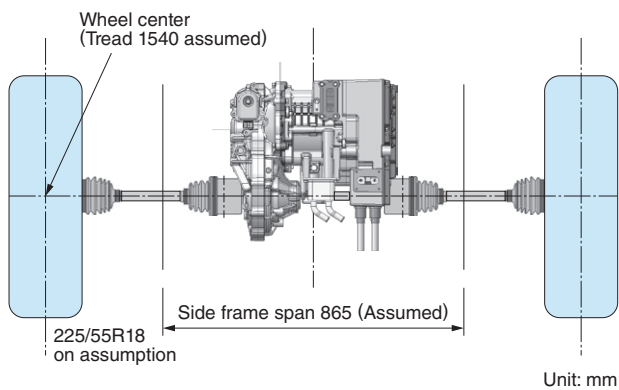
**3.3 Intermediate Shaft as Standard Equipment**

In the e-Axle (parallel axis gear type), the differential center and product center is not aligned because the drive shaft has a different length.



**Fig. 8 Curves of Driving Torque and Running Load**

It shows the continuous rated axle torque, running load curves for each gradient. The dots show the speed limits and running loads specified for various roads in the world.



**Fig. 9 Diagram of Mounting Equipment Relationship in Vehicle**

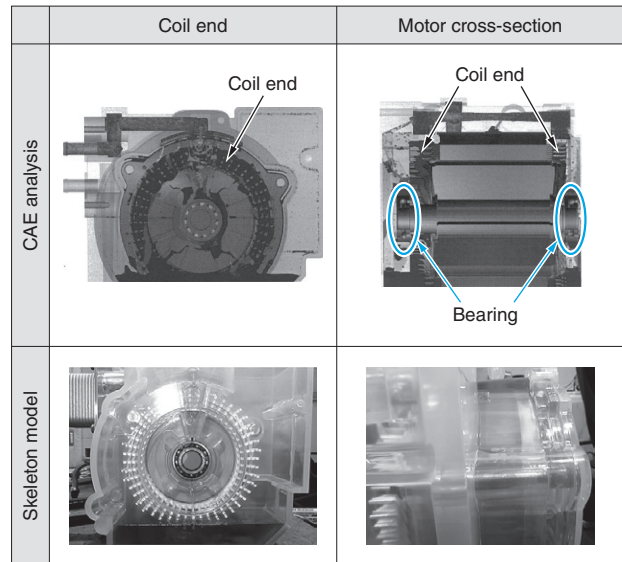
The vehicle on-board relationship diagram is shown in regard to tires, axles, and developed product.

When the intermediate shaft comes as a standard equipment, both the right and left drive shafts can be arranged to have the same length even though the e-Axle is installed in the center of the vehicle and the torque steer can be eliminated. Fig. 9 shows a diagram of the mounting equipment relationship in the vehicle.

## 4 System Components

### 4.1 Motor

The motor type is a permanent magnet synchronous motor. For the stator windings, flat wires are used for the purpose of downsizing. In order to attain a high continuous rated output, an adequate



**Fig. 10 Cooling Oil Fluid Analysis and Verification Test**

An example is shown about the CAE analysis and the result of comparison of actual oil flows using a skeleton model.

amount of cooling capacity is needed. Fluid analysis of the cooling oil and heat transfer analysis was carried out to optimize the oil cooling system. Fig. 10 shows the cooling oil fluid analysis and verification test. This is an example of Computer Aided Engineering (CAE) analysis and the comparison result in regard to actual oil flow using a skeleton model.

### 4.2 Inverter

#### 4.2.1 Construction

In order to realize a compact system, it is necessary to install an inverter close to the motor. Conversely, however, electronic parts allocated in the inverter are subject to exposure to a rigorous thermal environment because of the heat generated from the motor.

For solutions to such issues, a direct water cooling system is adopted for the Insulated Gate Bipolar Transistors (IGBTs), the parts in the inverter that generate high heat. In addition, an optimal cooling water path is established so that temperatures of chips within the module can be equalized. Smoothing capacitors, current sensors, and control circuit boards have a construction where their heat is dissipated through the casing and the cooling efficiency is raised by lowering the inner air temperature.

#### 4.2.2 Control

Regarding Controller Area Network (CAN)

communications for managing torque-related instructions and diagnostic information, it is equipped with an AUTOSAR-compliant communication software. The AUTOSTAR is a de facto standard in the industry. Based on this standard, we can make a control system with high reliability in a short time. It can be customized according to customer's individual requirements. Fig. 11 shows a control block diagram.

### 4.3 Gear

Fig. 12 shows a configuration diagram of a 3-shaft gears. For the gear box, because of good efficiency, a parallel-axis type (instead of the coaxial

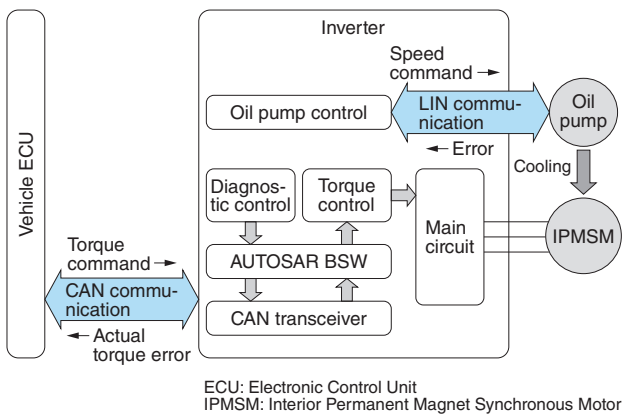


Fig. 11 Control Block Diagram

A control block is shown where the torque command of the vehicle computer is turned into the current command for the motor.

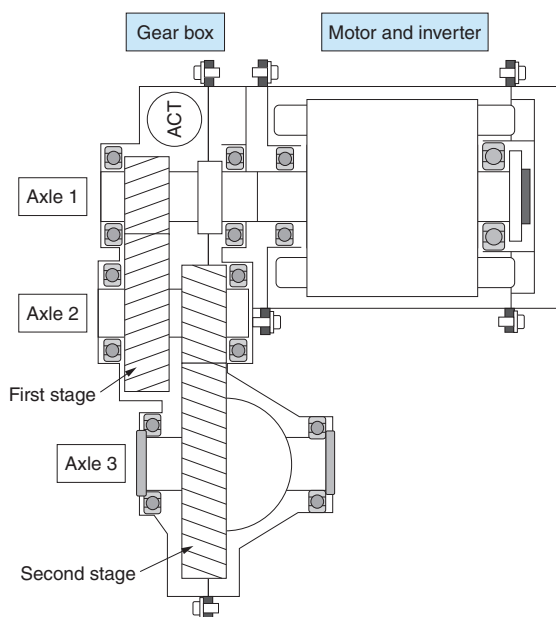


Fig. 12 Configuration Diagram of 3-Shaft Gears

A configuration diagram of 3-shaft gears is shown.

type) is used and a 3-shaft type is adopted for its good setup gear ratio and good layout. The gear box itself achieved a class-leading mass reduction.

### 4.4 Parking Lock

The vehicle is required to be equipped with a parking lock mechanism that is used to lock the drive shaft during parking. The e-Axle is equipped with a parking lock to improve further space saving and realize the reduction of the development period of a customer's product.

## 5 Evaluation System

We are manufacturing and supplying EV traction motors and EV evaluation systems (dynamometer testing systems). For the evaluation of the e-Axle, we built an EV powertrain evaluation system using absorption dynamometers combined with drive shafts on both right and left sides of the differential gears. This system is working at R&D Laboratory for Automotive Testing Services at Meiden Ohta Administration Office in Gunma Prefecture, Japan. Fig. 13 shows an overall view of the EV powertrain evaluation system.

This system makes it possible to evaluate dynamic performance under the assembled condition of the e-Axle together with gears using an actual axle. It is provided with EV batteries similar to actual batteries to be installed in a car, Vehicle Control Unit (VCU), and the running simulation software "CarSim". It can reproduce, for example, a measurement of energy consumption assuming actual running, running conditions under wavelike

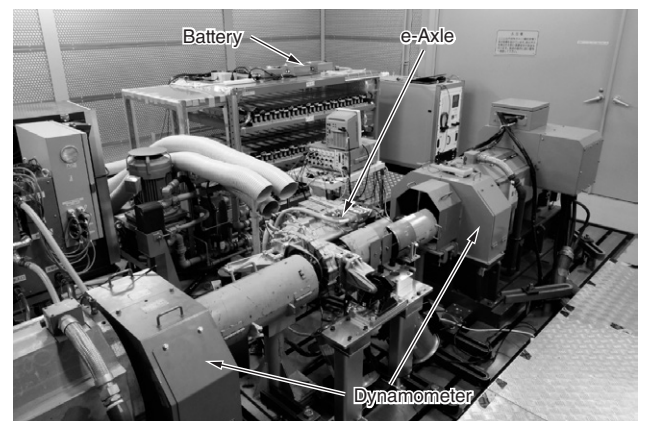


Fig. 13 Overall View of EV Powertrain Evaluation System

An overall view of the EV powertrain evaluation system used at R & D Laboratory of our Meiden Ohta Administration Office is shown.

passages and low- $\mu$  roads, and can confirm a parking lock function.

Through the presentation of our e-Axle and its evaluation system plus the result of driving simulation (evaluation result), our product will contribute in accelerating the speed of customers' technical development and in improving quality and safety.

## 6 Postscript

Through our system development activities for this time, we could produce below results:

- (1) Top-class output density (mass and volume) and continuous ratings.
- (2) By combining a high-speed motor and a high gear ratio, we realized a compact product that can be mounted in a narrow space under the 3-row rear seats.

In addition, by adopting a self-circulating oil cooling system, it promotes a highly versatile mounting design (applicable to different EV models).

- (3) It can realize an axle output evaluation test and vehicle running simulation test by using the e-Axle and EV powertrain evaluation system.

In response to requests from our customers

regarding installation layout, we will promote mass production of the e-Axle in the shortest possible time and make efforts to increase lineups for the 100 kW and 200 kW.

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- AUTOSAR is a trademark of Autosar Gesellschaft Burgelrichen Lechts.
- CarSim is the registered trademark of Mechanical Simulation Corporation.
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### (Note)

※1. Torque steering: An automotive phenomenon that a car tries by itself to turn even though the driver does not turn the handle. Such a phenomenon is caused by a difference in driving torque between the right and left driving wheels.

### 〈References〉

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