Compact and high-efficiency 1-axis e-Axle with a planetary gear set

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Summary

This article describes a compact e-Axle that was developed using a planetary gear set as the gearbox to improve vehicle mountability, expand luggage space, increase degrees of freedom for vehicle styling and reduce aerodynamic drag. The adoption of a stepped planetary gear set configuration and optimization of oil flow inside the unit achieve both excellent transmission efficiency and lubrication performance.

1. Introduction

The automotive industry is moving ahead with electrification of powertrain systems in the form of electric vehicles, hybrid vehicles and other types in order to achieve a sustainable society. Weight reductions, downsizing and improvement of electric powertrain efficiency are necessary and indispensable to promote their widespread diffusion with the aim of markedly reducing greenhouse gas emissions. Companies are developing e-Axles that integrate the motor, inverter and gearbox into a single unit.

This article describes JATCO's new e-Axle with a 1-axis structure that uses a planetary gear set to build a more compact unit with higher efficiency. Special focus is put on explaining the gearbox.

2. Development aims

The following three aims were set for the development of the new 1-axis e-Axle.

(1) To achieve the top benchmark for volume by substantially downsizing the unit in the vehicle's longitudinal and vertical directions.
(2) To aim for top-level transmission efficiency.
(3) To adopt a lubrication system without an oil pump so as to achieve a low-cost, compact unit.

Downsizing the e-Axle provides the following benefits for the vehicle (Fig. 1).

- Mountable regardless of 2WD/4WD.
- Expansion of luggage space.
- Assurance of crumple space for collision safety.
- It allows a lower hood height, increasing the degrees of freedom for vehicle styling and reducing aerodynamic drag.

3. e-Axle specifications

3.1 Major specifications

The major e-Axle specifications are listed in Table 1. The appearance of the new e-Axle is shown in Fig. 2

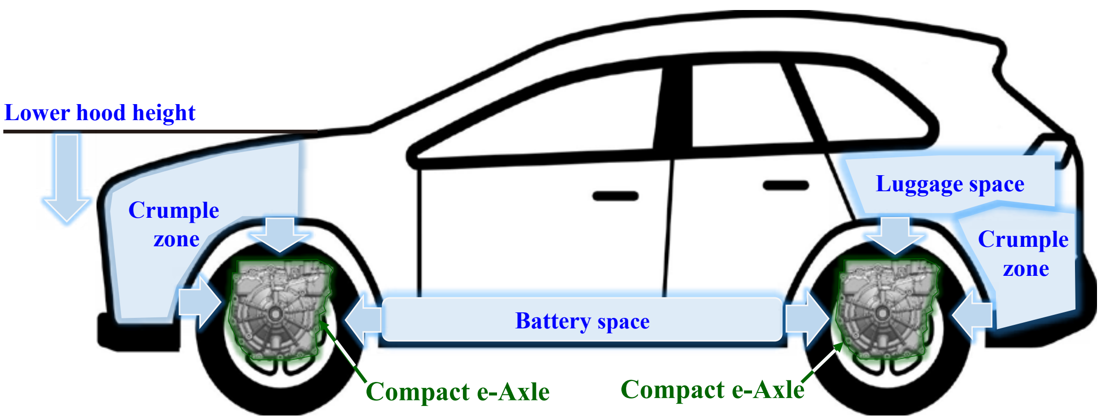

Fig. 1 Benefits for the vehicle of compact e-Axle

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Table 1 e-Axle specifications

Max. electric motor power	150 kW
Max. electric motor torque	320 Nm
Max. electric motor speed	13,000 rpm
Gear ratio	9.692
Unit volume	65 L
Unit size	X:325 mm×Y:540 mm×Z:370 mm

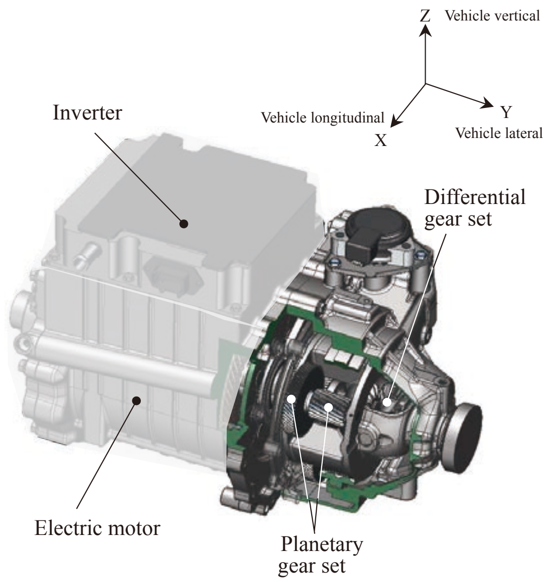


Fig. 2 Appearance of new compact e-Axle

3.2 Aim of downsizing

As illustrated in Fig. 3, the dimension in the vehicle's longitudinal direction was shortened by adopting a single-axis structure.

The e-Axle achieves the top benchmark for torque density as shown in Fig. 4.

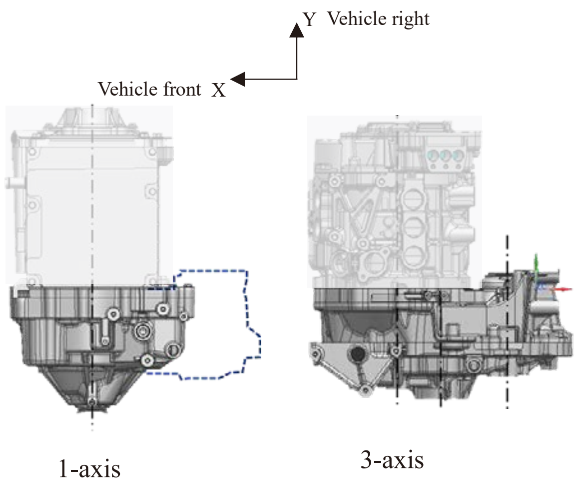


Fig. 3 New compact 1-axis e-Axle

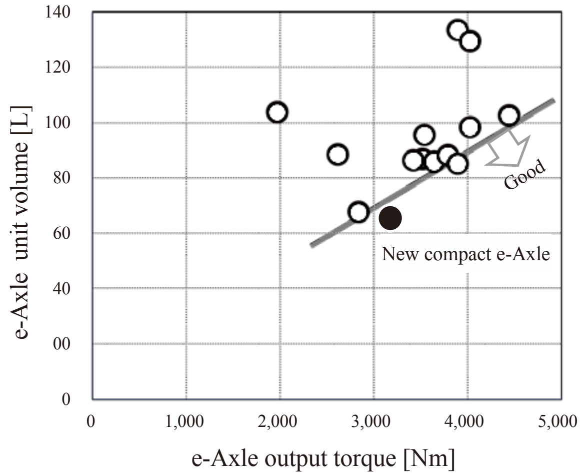


Fig. 4 e-Axle torque density

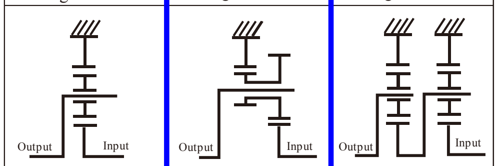
4. Gearbox

4.1 Gear specifications

As shown in Fig. 5, a stepped planetary gear set was adopted as the gear specifications in consideration of the following requirements (Table 2).

(1) It must allow a gear ratio of 9.4 or higher to be secured in consideration of the required driving force and available motor torque.

Table 2 Planetary skeleton selection

− / + / ++ Good	Single planetary gear set	Stepped planetary gear set	Dual planetary gear set
			
Gear ratio	−	+	++
Axial length	++	+	−
Efficiency	+	+	−

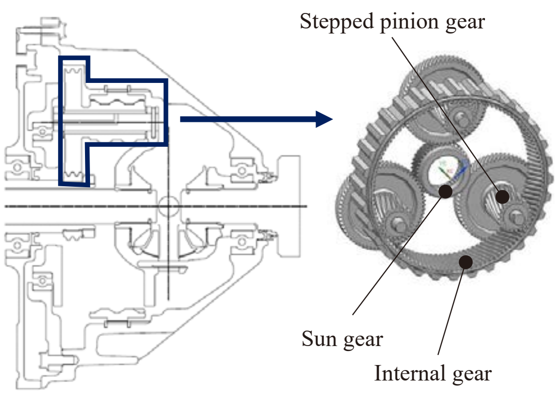


Fig. 5 Stepped pinion planetary gear set

(2) Compact axial length.
(3) Top-level transmission efficiency.

4.2 Gear ratio selection

Increasing the gear ratio reduces motor torque, enabling a smaller motor and inverter. However, increasing the gear ratio enlarges the radial dimension of the planetary gear set.

Motor torque was reduced by increasing the gear ratio of the new e-Axle to 9.692, the maximum dimension that would still allow the unit to be mountable (Fig. 6).

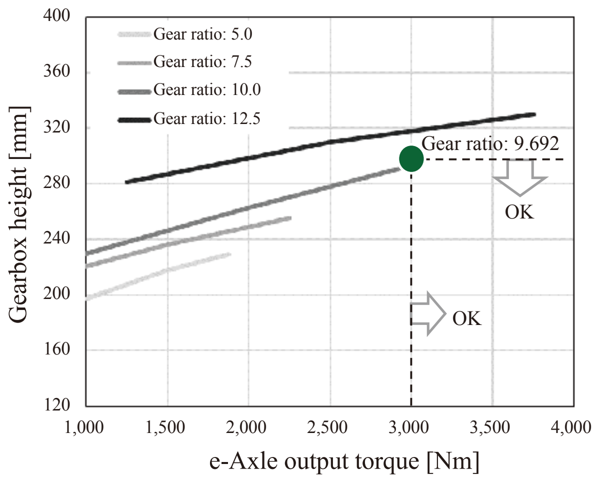


Fig. 6 Gear ratio optimization

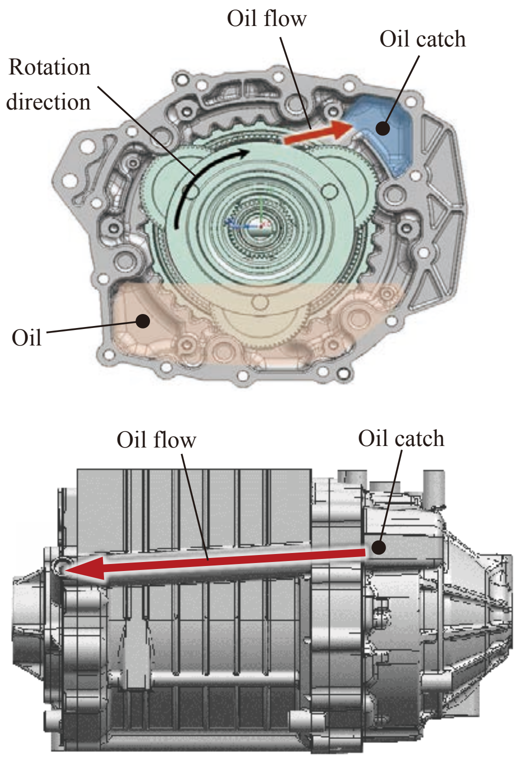


Fig. 7 Oil flow

4.3 Gear lubrication system

A lubrication system was adopted that uses oil churning by the gears to lubricate each part, thus achieving a low-cost, compact system.

4.3.1 Distribution of lubricant

The structure shown in Fig. 7 was adopted to optimize lubrication based on oil churning by the gears. It incorporates improvements regarding oil supply destinations, churning method, flow passages and circulation method.

An oil catch is provided that retains the oil churned by the planetary gears and distributes it to the bearings and seals of the gearbox output shaft positioned on the opposite side from the gearbox.

4.3.2 Results of lubrication simulation

Oil flow inside the unit was simulated using computational fluid dynamics (CFD) simulation software. The results confirmed that lubrication was reliably provided to each part as shown in Fig. 8. It is observed that oil flows into the oil catch and is well distributed to lubricate the planetary gears. In addition, an experiment was conducted to visualize the oil flow. The experimental data validated the simulation results and the validity of the lubrication system.

4.4 Transmission efficiency

The following elements that greatly influence the sensitivity of transmission efficiency were incorporated into the design to reduce loss compared with that of a 3-axis gearbox structure.

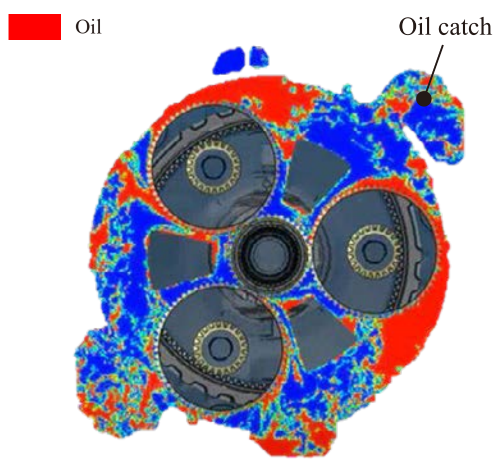


Fig. 8 Oil flow simulation

Gear meshing:
The adoption of the stepped planetary gear set achieved the same number of meshes as that of a 3-axis structure.

Bearings:
The stepped planetary gear set eliminated the tapered roller bearings and reduced the number and load of the ball bearings.

Oil churning:
The oil catch structure reduces churning resistance.

As shown in Fig. 9, these measures reduced the friction loss of the 1-axis unit to nearly one-half that of the 3-axis gearbox to provide top-level transmission efficiency.

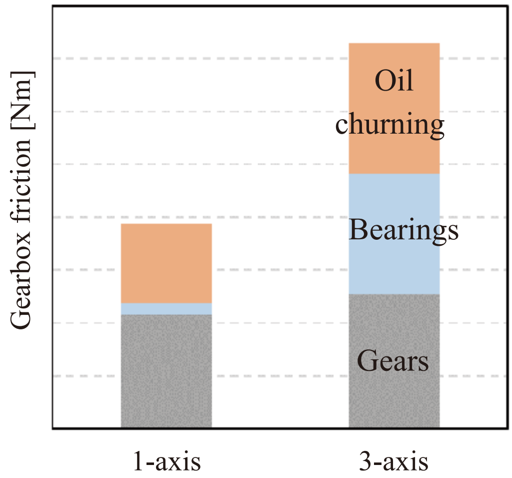


Fig. 9 Gearbox friction reduction

5. Conclusion

A compact e-Axle was newly developed that adopts a planetary gear set as the gearbox, which improves vehicle mountability, expands luggage space, increases the degrees of freedom for vehicle styling and reduces aerodynamic drag.

The adoption of a stepped planetary gear set structure and optimization of oil flow inside the unit achieve both excellent transmission efficiency and lubrication performance.

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