Technical Trends and Outlook for Automotive Driveline System for Electrification

H. MAKI

With the electrification of vehicle powertrains, the requirements for drive units and systems are also changing significantly. Specifically, it is necessary to develop drive units and systems that respond to changes in power characteristics and responsiveness due to motors, changes in the configuration of the entire powertrain, and changes in mounting requirements. This paper introduces the current status and prospects of technologies for electrification in drive shafts, hub units, differential units, and torque control devices (TCD). We will also introduce our gear and bearing efforts to increase the speed and reduce the size of the eAxle. Finally, we will introduce efforts to optimize the design of the drive system in order to satisfy the three conflicting elements of fuel efficiency, driving performance, and NV at a high level.

Key Words: *electrification of automobiles, driveline system, drive shaft, hub unit, torque control device (TCD), differential unit, carbon neutral, realization of a safe and comfortable society*

1. Introduction

The automotive industry is developing technologies to respond to the once-in-a-century transformation for realizing a carbon-neutral, recycling-oriented, safe and comfortable society. As the powertrains of automobiles become electrified, the requirements for the driveline systems and units that handle the driving and turning of vehicles are changing significantly. Changes in the power characteristics and responsiveness of motors, changes in the configuration of the entire powertrain (changes in the amount and arrangement of rigidity, gap, and inertia), and changes in mounting requirements have led to strong demand for improved performance in terms of driveline system safety, reliability, driving, NV (Noise & Vibration), and cruising distance. To take this evolution to an even higher level, reliability and cost reduction are essential, but it is also important to address modifications such as improvements of electric power consumption (loss reduction, lighter weight), mountability (smaller size), low NV, and added value (four-wheel drive, torque control devices, etc.). To achieve this, we must have a deep understanding of customer expectations and maximize JTEKT's accumulated strengths to conduct technological development of the driveline system as a whole (**Fig. 1**).

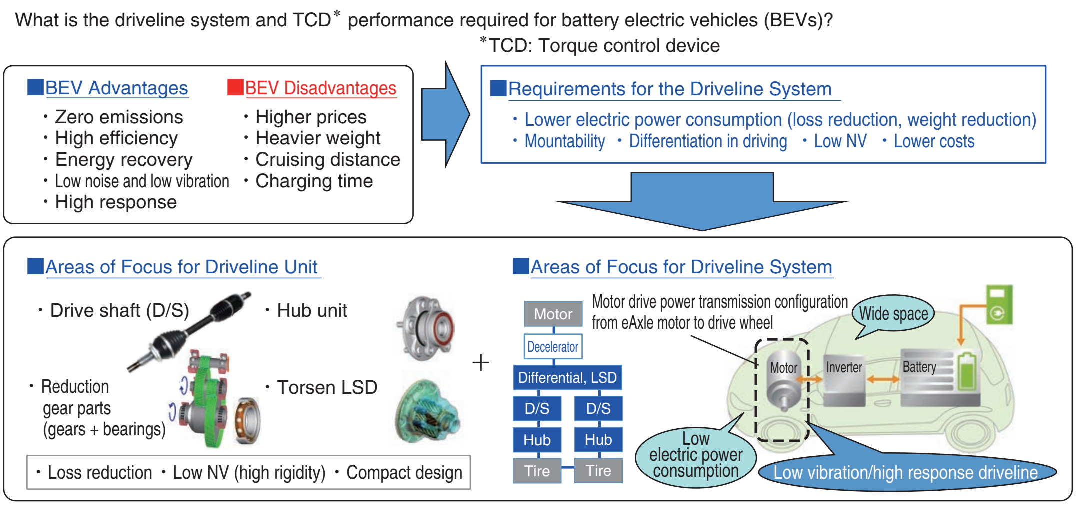


Fig. 1 Advantages and disadvantages of BEV (Battery Electric Vehicle) and demands on driveline system

This report presents the technological development trends in the electrification of driveline units, the approach to driveline systems for "No. 1 & Only One," and their future prospects.

2. Development of Driveline Units

2. 1 Drive Shaft Improvement Measures

A low-friction-loss type joint (XBJ) with an opposing groove structure has been developed to reduce drive shaft loss (see **Fig. 2** "Developed Product"). To reduce the frictional resistance with the outer ball in cage, the specifications of the factors contributing to the cage axial load were reviewed, and a lower loss torque and bending rigidity were achieved using an opposing groove structure (see **Fig. 2** "Development Objectives").

2. 2 Hub Unit Improvement Measures

Figure 3 shows the measures implemented for improving efficiency in the hub unit. The hub unit, which transmits the driving force of the drive shaft to the wheel, accounts for approximately 1.3% of the fuel usage in four-wheeled vehicles, and needs for lower torque and lighter weight are growing.

To reduce the torque, a low-viscosity base oil grease was used to reduce rolling resistance, resulting in a 40% reduction in rotational torque at the bearing by reducing the agitation resistance. The lubrication function of the grease is also maintained by optimizing the additives to ensure the oil film thickness. The number of seal contacts has been decreased to reduce the contact resistance of the seal lip, and the torque at the seal portion has been reduced by 75%. Also, a labyrinth and gutter structure is used to reduce water exposure at the lip, ensuring sealing performance equivalent to or better than the current seal.

Also, by optimizing the heat treatment conditions, residual compressive stress was applied to the weakest part of the shaft to achieve a 7% reduction in the weight of the shaft while maintaining its strength.

2. 3 Differential Unit Improvement Measures

Torsen LSD technology for further advance and size reduction, which has proven as a high performance differential for high power 4WD vehicles and sports cars, was incorporated in the JTEKT Ultra Compact Differential (JUCD) by adding new knowledge of gear design and machining technology.

The JUCD has a revamped differential gear structure. Compared with the bevel gear differential, the differential strength is more than twice as high for the same volume of the differential gear functional part because the tooth width for each meshing of the differential gear and the meshing number with the output gear has been increased. A high torque density of less than half the required volume is achieved for the same differential strength (**Figs. 4** and **5**).

This JTEKT Ultra Compact Differential (JUCD) will contribute to the design of more compact structures for the eAxle and will greatly increase the flexibility of the eAxle's installation into vehicles.

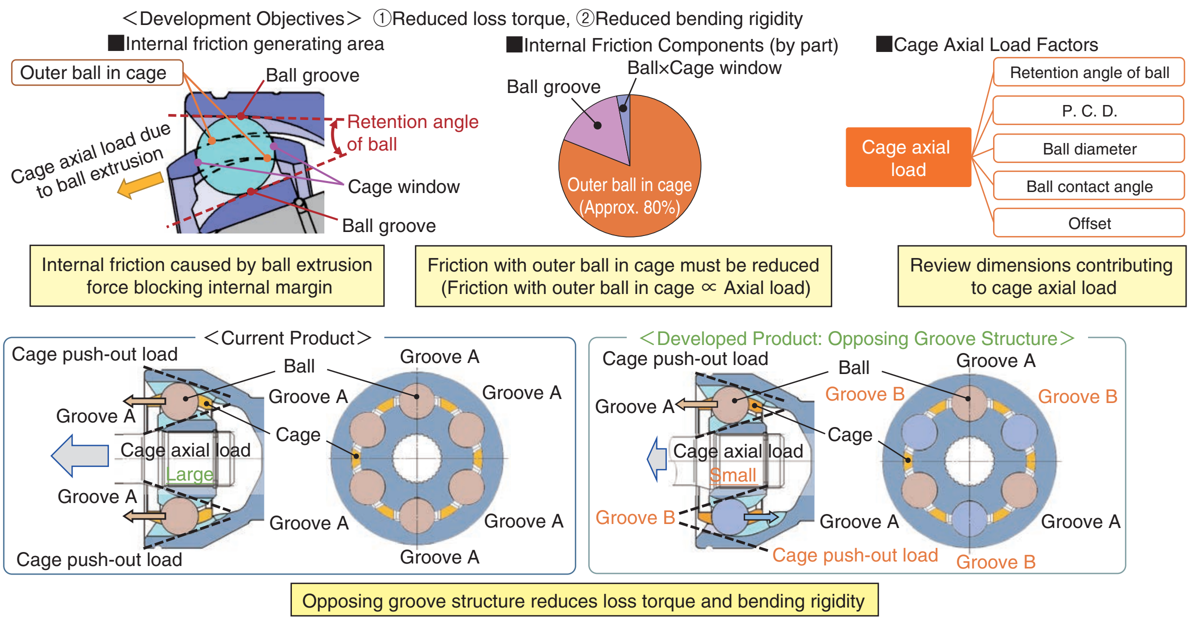


Fig. 2 Activities to improve the efficiency of drive shaft (opposed groove structure)

2. 4 Torque Control Devices for Providing Further Loss Reduction

JTEKT's No. 1 and Only One product, the Torsen LSD (Limited Slip Differential), is a type of limited slip differential with excellent response due to its torque-sensitive.

The Torsen Type-D has an innovative differential gear structure, and the width, which had been an issue, is much shorter for making it easier to install in a vehicle. When installed in xEVs (collective term for BEV, HEV, and other electric vehicles), in addition to providing the turning performance and rough road drivability required of conventional differential limiting devices, the Torsen LSD also improves start-up acceleration and reduces the frequency of ESC (Electric Stability Control) intervention, thereby reducing the loss of driving force transmission and improving electric power consumption. Compared to an open differential, the Torsen LSD contributes to lower electric power consumption by suppressing tire slip and expanding the regenerative braking area even in slippery driving conditions.

The differential is designed to be advantageous for future installation of the eAxle unit, and will not only contribute to safe and secure driving and driving pleasure but also provide new added value to electric vehicles with its contribution to lower electric power consumption (**Fig. 6**).

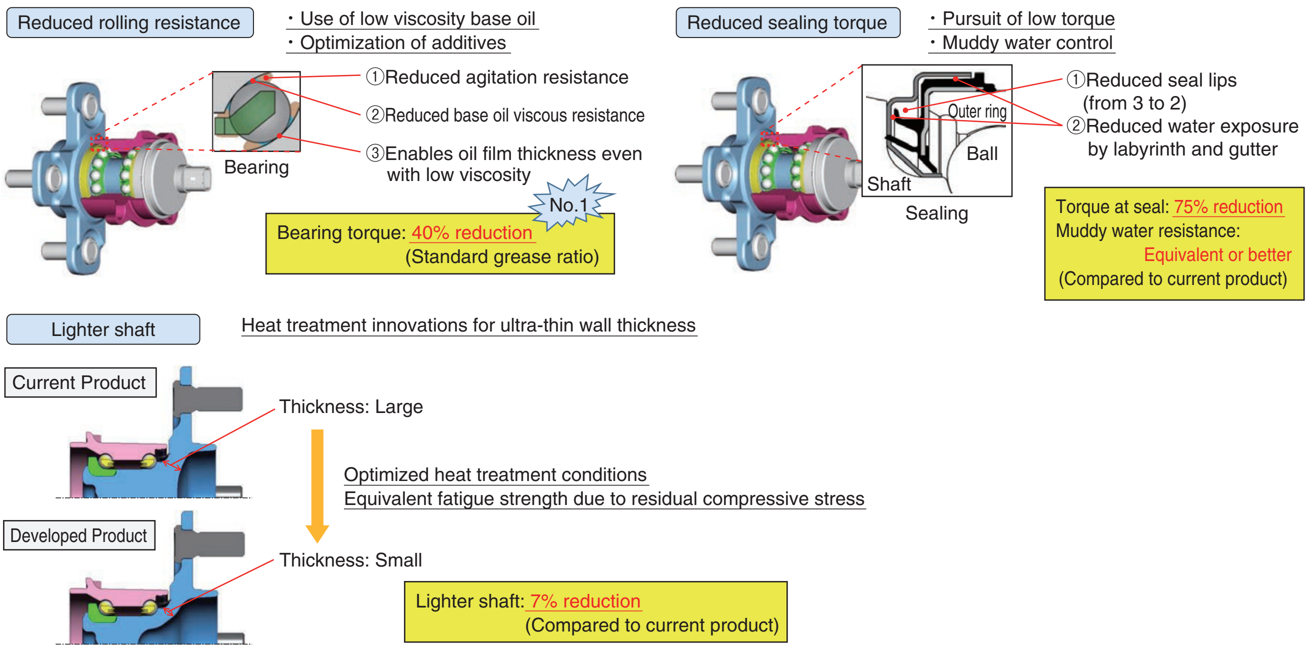


Fig. 3 Activities to improve the efficiency of hub unit

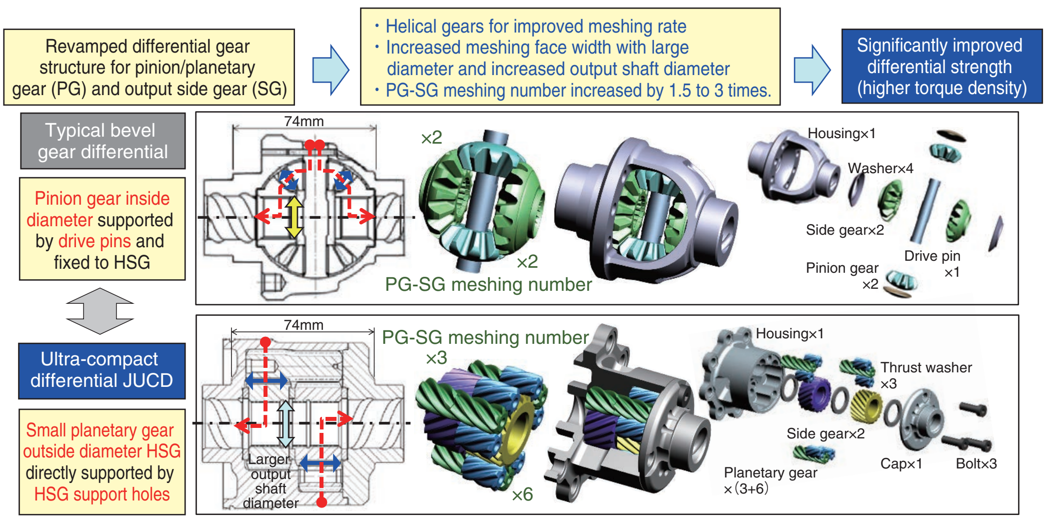


Fig. 4 Differential gear structure of JUCD (compared to bevel gear differential)

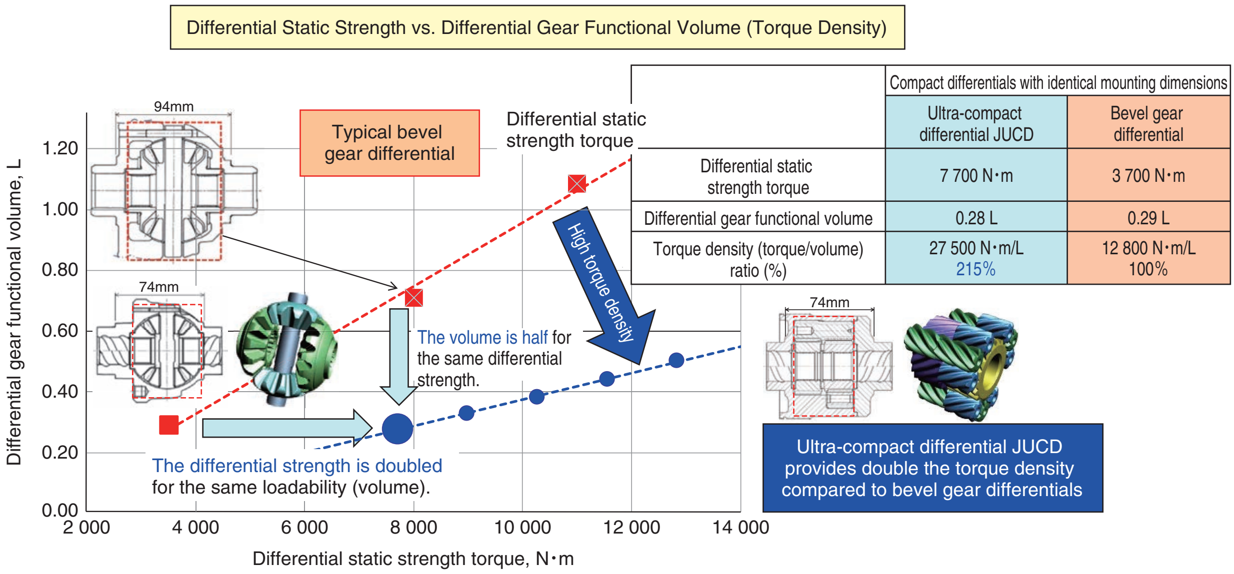


Fig. 5 Torque density of JUCD (compared to bevel gear differential)

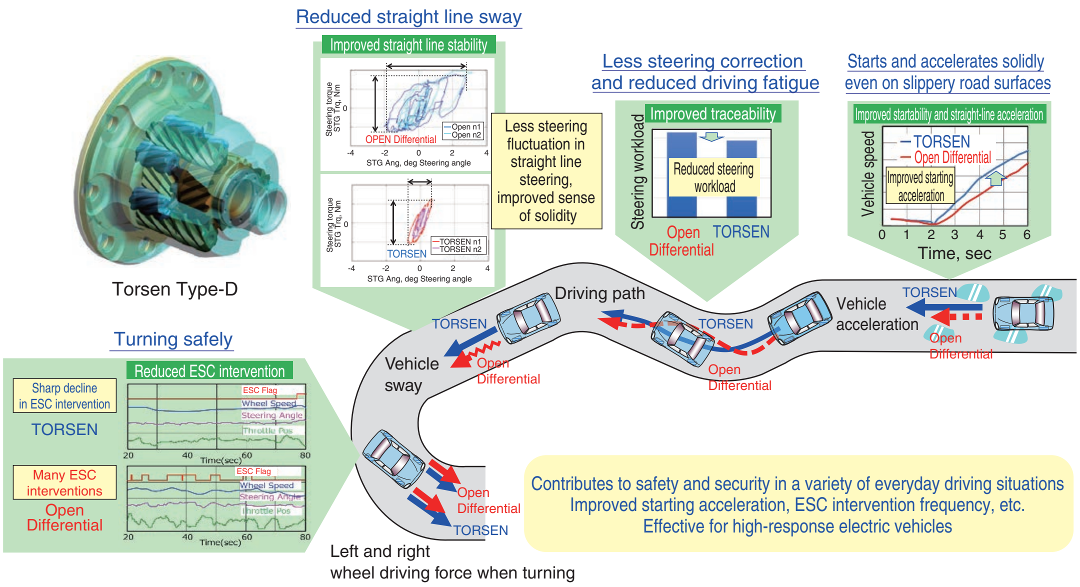


Fig. 6 Contribution of Torsen LSD to electric vehicles

2. 5 Gear and Bearing Improvement Measures

To enable increasing rotational speed and compact design of eAxle, the gears and bearings themselves need to be downsized. For this reason, the JTEKT Group is working on technology to freely control the tooth face shape by utilizing the gear and bearing analysis and design technology and the gear machining technology that it has developed over the years. For example, low NV and improved durability can be expected by performing 3D tooth surface modification such as end relief and bias correction (**Fig. 7**).

3. Creation of New Added Value

3. 1 Driveline System Improvement Measures

Customers are asking for not only the performance of the driveline unit itself, but also improvement of the function and performance of the driveline system and the vehicle system as a whole. There are three conflicting factors that determine the added value of the entire vehicle system: fuel consumption, driving, and NV as shown in the left diagram in **Fig. 8**. JTEKT is conducting optimization studies to satisfy these requirements at the highest level. For example, from the standpoint of providing safe and secure driving and driving pleasure, we are conducting comprehensive studies on the effects

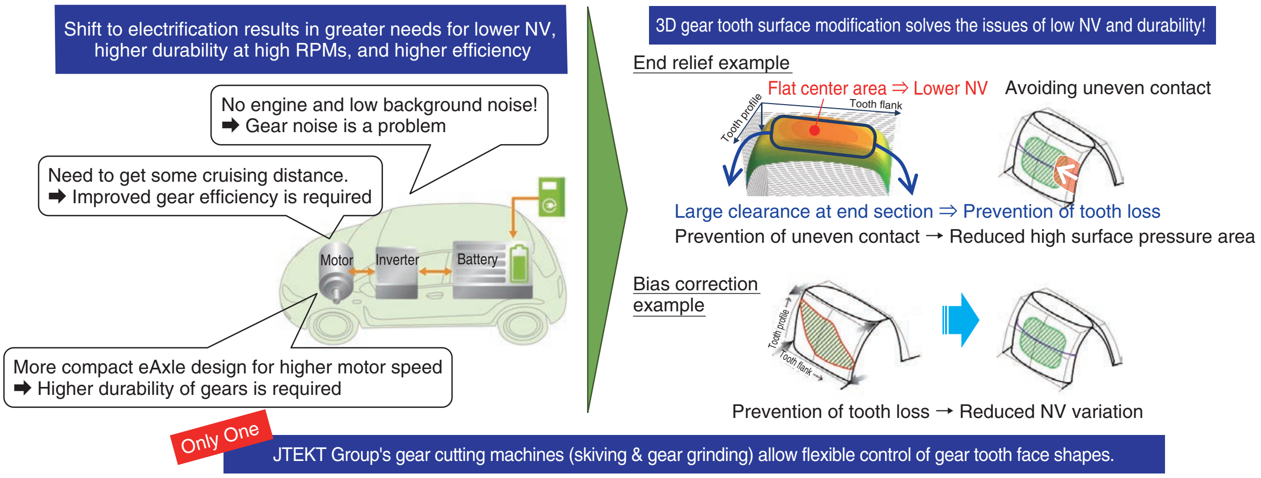


Fig. 7 Gear/bearing activities

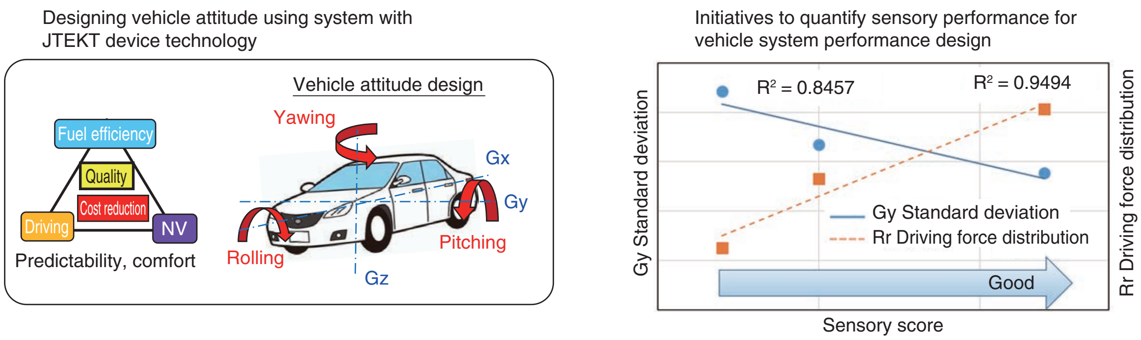


Fig. 8 Activities as a vehicle system

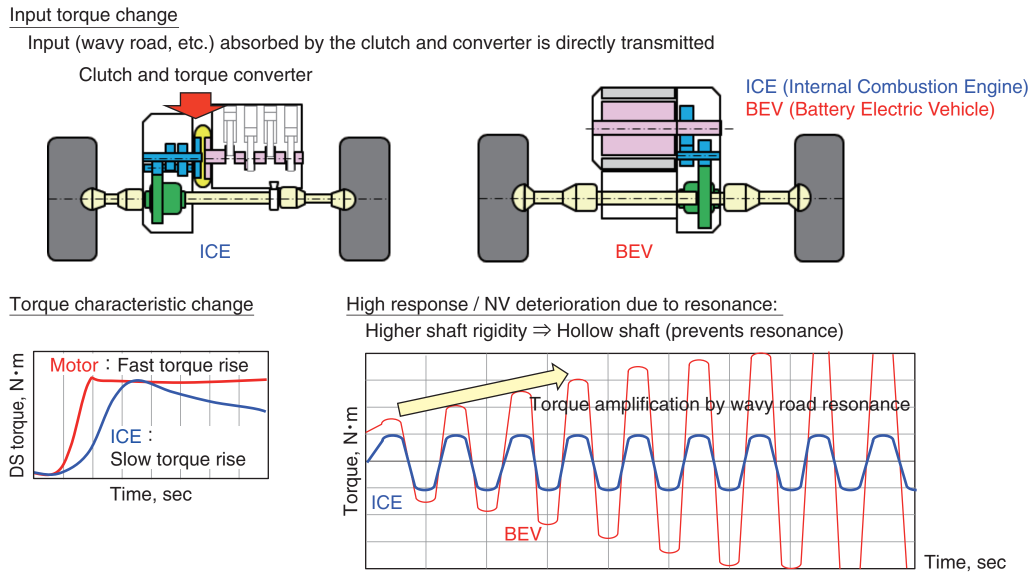
of the driveline unit and steering on various parameters of the vehicle attitude. The right diagram in **Fig. 8** shows a case study on the relationship between the sensory score (feeling dizzy) at taking-off and the vehicle dynamic performance because of the front-rear driving force distribution. There is a strong correlation between the sensory score (feeling dizzy) and the standard deviation of Gy (lateral acceleration), and it is verified that increasing the distribution of the driving force to the rear wheels is effective.

We will continue to improve our strengths in pursuing safe and secure driving from the vehicle's point of view and to propose new added value.

3. 2 Vibration Reduction Measures

Vibration phenomena of battery electric vehicles (BEVs) are greatly affected by changes in the excitation force of the prime mover and the vibration transfer system, and many efforts are required to realize vehicles with high quality, low cost, and low NV. The change in torque excitation force is due to the faster rise in drive torque as the vehicle becomes more motorized. Although this improves the acceleration performance, measures at taking-off must be needed to handle the high torque and worsen vibration due to high responsiveness.

And idle vibrations disappeared with no engine, which eliminates the need for idle vibration prevention measures that have been an issue with conventional internal combustion engines (ICEs). On the other hand, although in ICE vehicles, vibrations from the tire side was absorbed by the clutch and torque converter, the motor in BEV is directly connected to the tires. In particular, the road reaction forces are directly input to the drive shaft and amplified by torsional resonance on wavy roads, which significantly deteriorates NV performance. So it is necessary to study reduction for the vibration transfer system. Development is rapidly proceeding on a unit that increases the rigidity of the drive shaft to prevent resonance and that reduces NV by low exciting force in the high-torque renge. Utilizing the strengths of having gears, Torsen LSD, hub units, and drive shafts, JTEKT are strengthening our activities as a driveline system (**Fig. 9**).



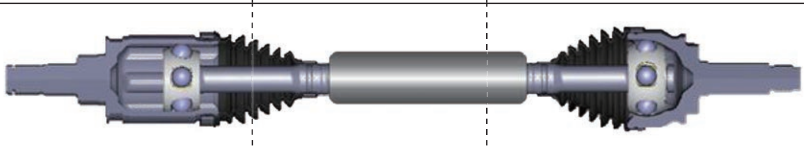
	Inboard joint (differential side)	Shaft	Outboard joint (tire side)	Hub
				
Vehicle expected value	1) Vibration at startup 2) Improved mounting flexibility (Compact size, wider regular angle, improved durability)	1) Starting/acceleration performance	1) Improved fuel efficiency/lower power costs 2) Improved mounting flexibility (Wider regular angle, improved durability) 3) Quality (NV)	1) Improved fuel efficiency/ lower power costs 2) Maneuvering stability 3) Quality (NV)
Unit requirements	1) Low coercive force 2) Wider regular angle: Durability	1) High rigidity Both increased rigidity and reduced weight (w/ lower cost)	1) High efficiency 2) Wider regular angle: Durability 3) Quality (clicking sound)	1) Low torque 2) High rigidity 3) Quality (pressure resistance marks, clinking sound)
Achieved technology	① Compact design technology	② Low-cost hollow shaft	③ Hub CVJ system for improved performance (efficiency and quality)	

Fig. 9 Changes in the vibration phenomenon of electric vehicles and unit development activities

4. Conclusion

In this report, the current state and future of drive shafts, hub units, torque control devices, and differential units were presented in the ongoing rapid shift of vehicles to electrification. JTEKT is aiming to become the world's leading supplier of driveline systems for realizing a carbon-neutral, safe and comfortable society and is committed to develop products that it can be proud of as No. 1 and Only One. Although it is not included in this report, we are also working on the downsizing, weight reduction, and performance improvement of high-pressure hydrogen valves and pressure reducing valves installed in fuel cell system vehicles for contributing to a hydrogen society.

The JTEKT Group will continue to combine its strengths to identify trends in the major transformations taking place daily in the automotive industry, strengthen its technology and development systems with an eye on the future, and contribute to global environmental responsiveness and improved safety.

H. MAKI*

* Chief of Business Field