

Development of Three-wheel Electric Vehicle Series for Expanding Application to Delivery Business

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ABSTRACT

Honda has recently developed three-wheel electric scooters for commercial use to reduce CO₂ emissions from the transportation sector and to respond to the growing demands for motor vehicles for delivery services. In the conventional three-wheel scooter series using a gasoline engine, there has been two types of cargo carriers; the one having the carrier as an integral part of the main vehicle body that tilts when the scooter leans and another one having the carrier on a non-tilting carriage in the rear. In our attempts to electrify both types of three-wheel scooter, we suggested an idea of making the electric powertrain common to keep the production cost low. Accordingly developed is the high-efficiency powertrain that enhances driving performance while making the vehicle more user friendly. The increased number of gears in the drivetrain coupled with the need for a differential gear for the two rear wheels also increases the backlash (free play), which causes issues such as vibrations and hammering noises. To deal with these issues, the electric power controller is programmed to apply a light torque to the drivetrain to take up the free play when the throttle is fully closed. Thus developed is the quiet, low vibration, and powerful electric three-wheelers appropriate for delivery services.

1. Introduction

The reduction of CO₂ emissions has been a worldwide issue to tackle for quite a while to slow global warming. As a means to deal with the issue, the electrification of motor vehicles is taking place rapidly. In the motorcycle sector of Honda, electric scooters were introduced in the market several times since 1994. After the repeated experimental practices toward popularization of electric scooters for commercial use since 2010^{(1), (2)}, the BENLY e: was introduced into the market in 2020⁽³⁾. The introduction of BENLY e: is an indication of possible CO₂ reduction from the transportation sector. A spread of electric scooters is starting mainly in the post offices for mail delivery. That in mind, in our attempts to further expand the electric scooter line up, we focused our attention on the three-wheelers that have a high demand for commercial use.

Due to an increase of demand for home delivery and catering from the “stay home” campaign to deal with Covid issues, the sales are increasing in utility motorcycles and scooters, especially the three-wheelers (Fig. 1). However, when applying an electric powertrain to three-wheelers, there were issues such as a higher production cost due to an increase of the number of parts and the vehicle weight and a lower electric power efficiency than in the two-wheel

counterpart. To clear up the said issues and respond to the demands, we have recently developed the utility three-wheelers; GYRO e: and GYRO CANOPY e: which are more user-friendly than ever due to the application of the electric powertrain (Fig. 2). Described in this paper are how the utility three-wheelers are used and how the scooters have evolved from the gasoline engine type to the electric type from technical perspectives.

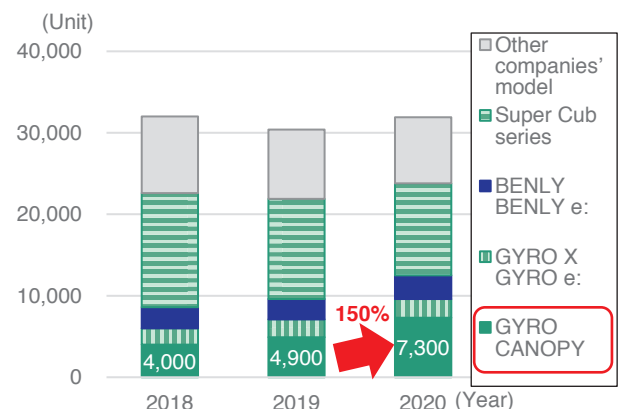


Fig. 1 Sales results of moped type 1 business category

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Fig. 2 Honda e: business-use electric scooter series

2. Current Status and Issues in Delivery Business

Upon the application of electric powertrain to the utility three-wheelers, we focused our attention on the cargo capacity, which is critical in the delivery business, and the impacts to the surroundings at the time of delivery.

2.1. Characteristics of Conventional Three-wheel Scooter Series

Regarding the already existing Honda GYRO series three-wheelers using a 50 cc gasoline engine, the basic model GYRO X was first introduced in 1982, and the variations GYRO UP and GYRO CANOPY were added later on. The characteristics of GYRO series is the Neidhart rubber coupling⁽⁴⁾ that connects the single-wheel front unit to the two-wheel rear unit. The front unit carrying the rider leans like a motorcycle when turning. On the other hand, the rear unit does not tilt and maintains both tires perpendicular to the road surface.

Depending on whether the cargo carrier is located on the front unit or the rear unit, the loading capacity and/or the direction of force on the cargo change. The basic model GYRO X and the GYRO CANOPY equipped with the large windscreen and the roof have a cargo carrier that tilts along with the vehicle body when turning. In this design, the cargo is less affected by vibrations and centrifugal force when running. Meanwhile in the GYRO UP, whose production was terminated in 2008, the large and low-floor cargo carrier parallel to the ground was located on the two rear wheels, which made this model suitable for transportation of large and/or heavy goods.

2.2. Types of Cargo on Current Three-wheelers

The cargos being delivered by the GYRO series can be roughly divided into the following two types according to the above-mentioned differences in cargo carrying characteristics.

Cargo (1): Bulky and heavy goods (beer case, box for tools and/or materials)

Cargo (2): Goods that should be kept from vibrations and/or centrifugal force (food, small appliance, etc.)

Figure 3 shows the share of various types of cargo on the three types of GYRO series models. The GYRO UP's large and low-floor cargo carrier parallel to the ground is suitable for the Cargo (1). On the other hand, the cargo carrier of GYRO X and GYRO CANOPY, which remains flat when stopping for loading or unloading and less affected by vibrations and centrifugal force when running, is appropriate for the Cargo (2). Moreover, the GYRO series allow locking of the rubber coupling by a single pulling of the lever when stopping to maintain stability of the cargo carrier. Due to this characteristics, the three-wheeler is much better when loading or unloading cargo than the two-wheeler. In consideration of a wide range of usability, the new electric three-wheeler was studied to be able to handle the above two types of cargo (1) and (2) when developing various types of new electric three-wheelers.

2.3. Consideration to the Surroundings and User Friendliness

As mentioned above, the commercial users of scooters are increasing due to the increase of demand for delivery services. To deal with demands of delivery at a specified time typical in food delivery, the scooter sometimes has to be operated in quiet hours such as early morning and/or late night. However, in the case of the three-wheeler powered by a 50 cc gasoline engine, which falls in the Class 1 motorized bicycle category in Japan, the noise is an issue especially at higher engine speeds when starting a loaded scooter. It has been clarified from the user interviews that the night-time delivery is voluntarily restricted in some regions to keep quiet for the residents. A quiet electric three-wheeler is a solution for the issues the delivery motorbike users have. On the other hand, there remains issues such as an increase of weight from carrying of large batteries as well

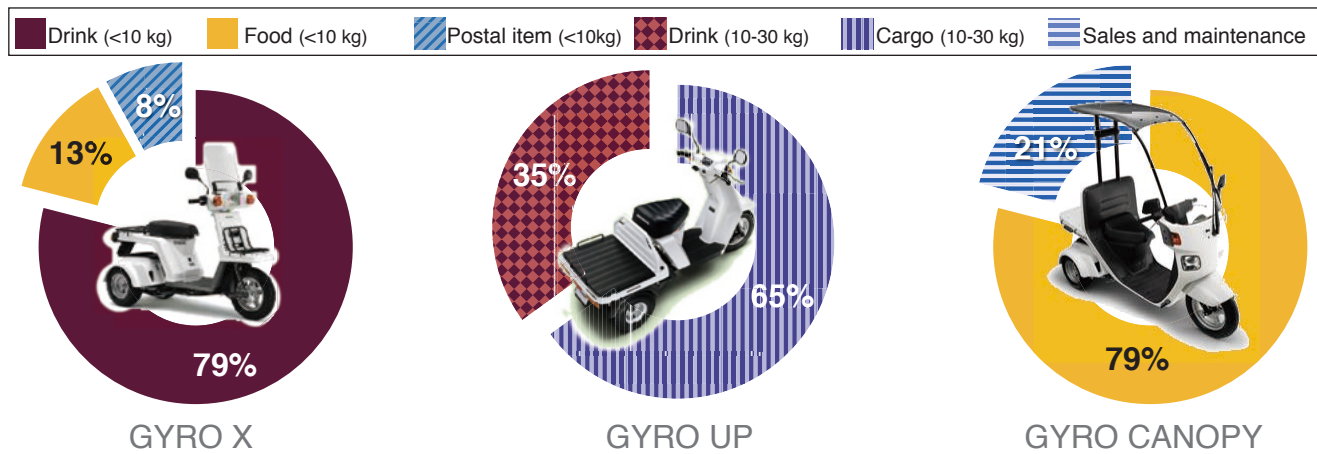


Fig. 3 Load composition ratio based on GYRO series owner survey conducted by Honda in 2018-2019

as in user-friendliness. The user-friendliness is crucial in the utility three-wheelers which are used by a wide variety of users such as part-timers who have only the regular automobile driver's license (which allows operating of 50 cc motorbikes in Japan). To live up to the expectations of the above-mentioned users, we set goals at an enhancement of driving performance and quietness as well as at a higher level of user friendliness by application of an electric powertrain.

3. Configuration of Electric Scooters for Delivery Services

Described in this chapter are the configuration of the scooters to deal with the earlier-mentioned manners of cargo carrying and the key points of advancement from the gasoline engine scooters.

3.1. Configuration of Scooter for Two Types of Cargo Carrying

As mentioned in the preceding chapter, the requirement differs depending on the manner of cargo carrying roughly classified into the types (1) and (2). To meet the requirement, two different configurations are necessary just like in the conventional models. Figure 4 shows the direction of force from the cargo in each type of configuration. For delivery of bulky and heavy goods (1), the non-tilting, low-floor cargo carrier is appropriate because the weight of cargo affects the rider less. For goods (2) that should be kept from vibrations and/or centrifugal force, e.g., for purposes such as food delivery, the tilting cargo carrier is appropriate because the cargo is free of side force and subjected only to the downward force when turning.

Keeping in mind the above mentioned, we chose to employ two different cargo carrier configurations while using a common electric powertrain for both GYRO e: and GYRO CANOPY e:. Figure 5 shows the common

powertrain and two types of cargo carrier. The electric powertrain is basically designed for GYRO UP having a large, low-floor cargo carrier in which the hurdles are higher such as the limited space and a higher strength requirement. Regarding the integrated motor, the same one as used in the two-wheeler BENLY e:I is employed. With those measures taken, the electric three-wheeler series have become a reality to respond to the various needs of cargo carrying while keeping the production cost at a low level.

3.2. Key Characteristics of Electrification of Powertrain

Bearing in mind the issues and requirements mentioned in the Chapter 2, the following two goals were set in this electrification project.

- Goal 1: To help ensure user-friendliness for various types of users, the new models have to be easier to handle than the gasoline-engine three-wheelers.
- Goal 2: Taking advantage of the torque characteristics of the electric motor, the driving performance should be enhanced.

Regarding the battery for driving of the scooter, the same quick changing system as in the BENLY e: called Honda Mobile Power Pack e: is employed⁽⁵⁾. This quick-change system allows extension of operating hours, which is a key requirement of commercial users. In the newly developed models, two units of Honda Mobile Power Pack

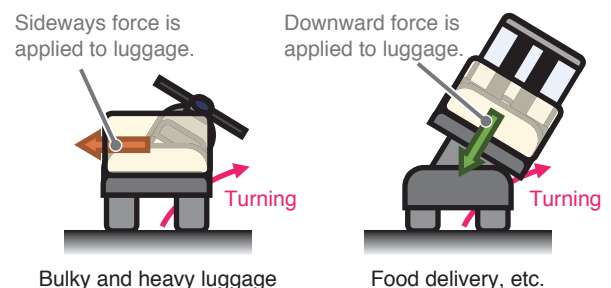


Fig. 4 Direction of force to cargo when turning

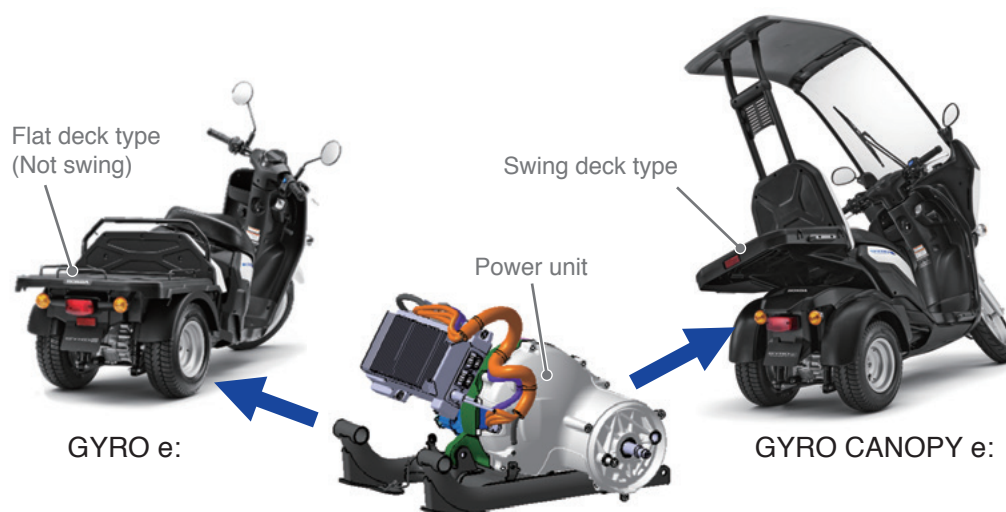


Fig. 5 Integrated power unit and each deck structure

e:, which weigh 10 kg per unit, are used.

The goal 1 “easy to handle” means easy man-handling of the vehicle. For easy handling, a low center of gravity (CG) of the vehicle is preferable because the lower the CG, the less the handling effort becomes if the handlebar height is the same. In the layout of electrical components, the one that large affects the CG height is the location of the batteries for the drive motor. To minimize effects of the batteries as heavy as approximately 20 kg to the handling, the battery packs are laid parallel in the proximity of vehicle’s CG under the seat just like in the BENLY e: (Fig. 6).

Also, for easier handling than the gasoline-engine model, the reverse assist that can be actuated from the button is equipped applying the control system derived from the BENLY e:⁽³⁾.

The goal 2 “enhancement of driving performance” is also a key requirement for enhancement of handling

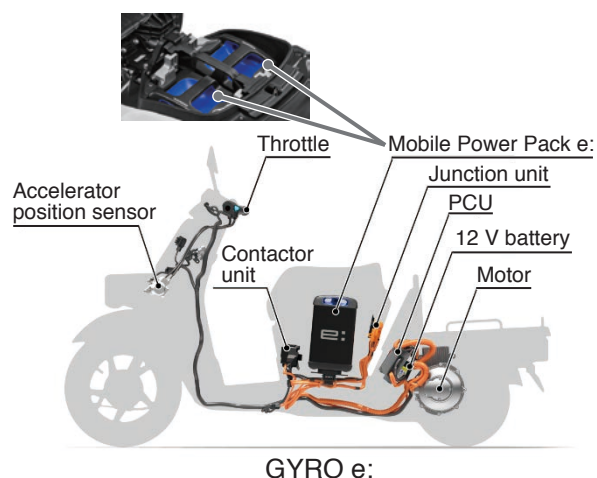


Fig. 6 Parts position of EV system

characteristics when carrying cargo. The details of enhancement of driving performance are discussed in the following chapter.

4. Measures to Deal with Technical Issues in Electrification

4.1. Higher Efficiency Electric Powertrain for Three-wheeler

Described hereafter are the measures to enhance the driving performance mentioned in the Goal 2, Section 3.2. As the maximum power output on the motor shaft is regulated for each vehicle category by the Road Transport Vehicle Act in Japan, it is necessary to enhance the efficiency of power transmission to the rear wheel to increase the power output on the rear wheel axle. Figure 7 shows the difference of transmission efficiency between

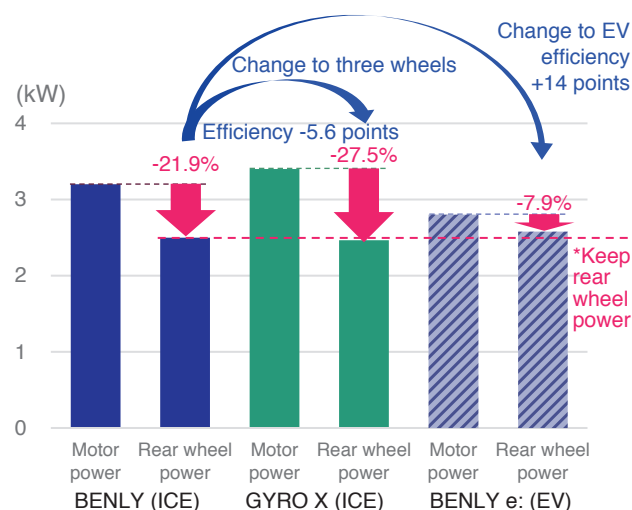


Fig. 7 Transmission efficiency by each model

the utility two-wheeler and three-wheeler using a gasoline engine along with the transmission efficiency of the utility electric two-wheeler. When the two-wheeler BENLY and the three-wheeler GYRO X both using a gasoline engine are compared, the transmission efficiency is lower by 5.6 points in the GYRO X having two driving wheels in the rear. On the other hand, when the two-wheeler BENLY using a gasoline engine is compared to the electrified version BENLY e:, the transmission efficiency is higher by 14 points in the electric version due to the unnecessary of the clutch and the use of gears instead of the belt-driven CVT. This realizes the same level of power output on the rear axle as the gasoline engine from the electric motor having a smaller power output on the motor shaft.

We have therefore employed the clutch-less gear drive transmission also in the three-wheeler to achieve a higher transmission efficiency than the gasoline engine three-wheeler. Regarding the differential gear important for a vehicle having two drive wheels in the rear, the component proven in the gasoline engine three-wheeler is employed as it is. Figure 8 shows the electric powertrain in which the clutch-less gear drive system developed in the electric two-wheeler is coupled with the components developed in the gasoline engine scooter. While the transmission efficiency lowers by 5.6 points due to the increase of the number of

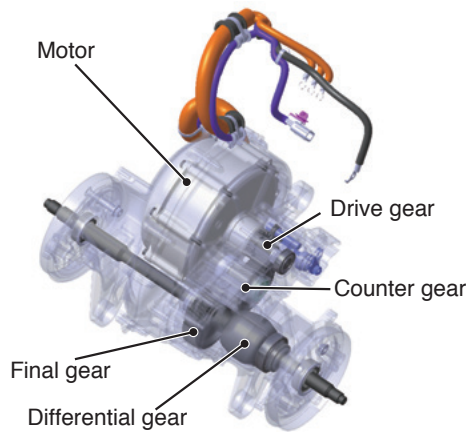


Fig. 8 Power unit for GYRO e:

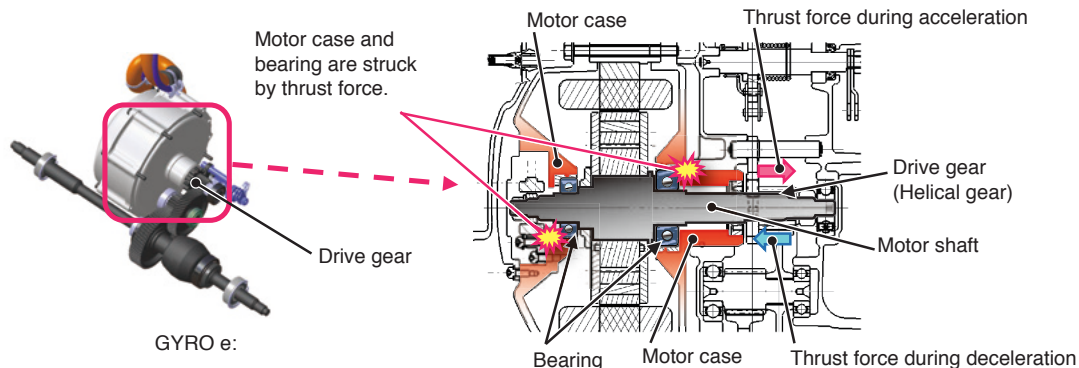


Fig. 10 Mechanism of hammering sound generation

drive wheels when the gasoline engine three-wheeler is compared to the two-wheeler counterpart, the lowering of transmission efficiency is as small as 2.0 points in the same comparison of electric models, resulting in an enhancement of transmission efficiency by 3.6 points in the electric three-wheeler (Fig. 9). With this higher efficiency transmission system employed, we have achieved 16% higher power output on the rear axle from the motor having the same motor shaft power output as the gasoline engine.

4.2. Considerations for Surroundings; Reduction of Noises and Vibrations

In the process of product development, the vibrations and the hammering noises were noticeable when accelerating and decelerating. These issues are due to the increase of total backlash resulting from the increased number of gears in the drivetrain from the motor shaft up to the rear wheel axle including the differential gear, which is non-existent in the two-wheeler. This phenomenon may occur when the force is applied to the motor shaft at the moment the driving starts from the momentary absence of contact between the gears when accelerating and decelerating. The vibrations and hammering noises may occur when the drive shaft rotor moves in the direction of thrust force from the helical gear, on which an abrupt force is applied, and touches on the case (Fig. 10). Figure 11 shows the difference of backlash in

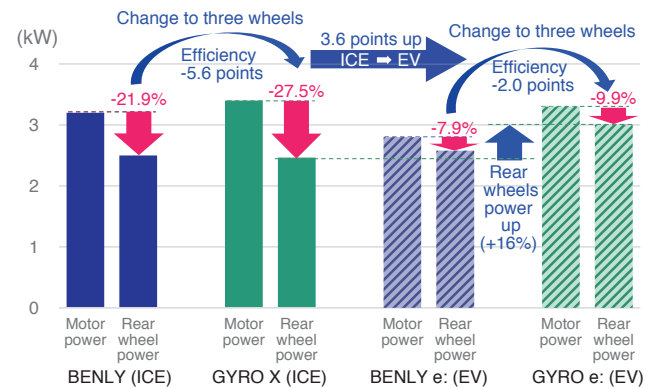


Fig. 9 Transmission efficiency by three wheels

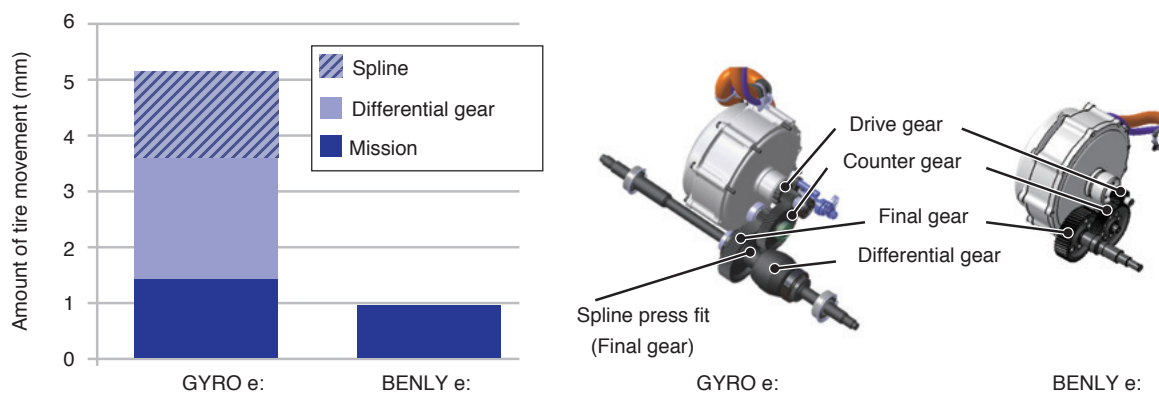


Fig. 11 Amount of backlash by each model

the electric two-wheeler and three-wheeler. In an attempt to control the hammering noises while maintaining the high-efficiency drivetrain as mentioned in the preceding clause, we suggested an idea of such a torque control that takes up the free play between gears. It is such a control in that a light torque is applied in the drivetrain to take up backlash even when the twist grip is fully turned off. Figure 12 shows the torque command of this control method. As shown, while the regenerative torque is applied when the twist grip is fully turned off in the two-wheeler, a light positive torque instead of a regenerative torque is applied only in the prescribed zone in the three-wheeler. The effect on the electric power consumption is minimized (5% more) by the minimization of torque to take up backlash and the optimum setting of the zone the torque is applied. Figure 13 shows the changes of

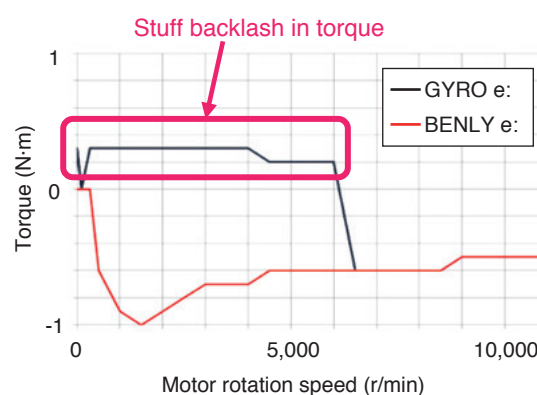


Fig. 12 Forward rotation torque command (Throttle closed)

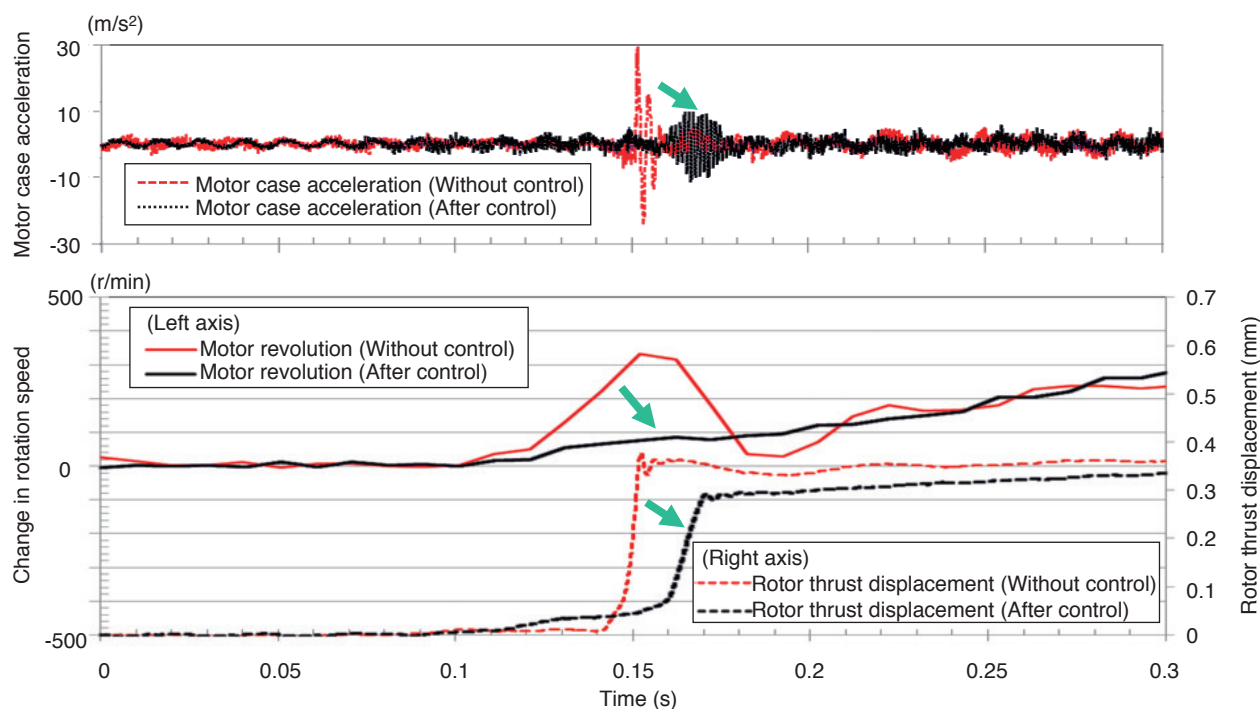


Fig. 13 Changes in conditions before and after countermeasures

characteristics from the backlash controller. Figure 14 shows noise reduction effects. As the graph in the middle of Fig. 13 shows, the addition of the torque to take up the free play between the gears help reduce abrupt changes of spinning speed and slows rotor displacement in the thrust direction as the lower graph in Fig. 13 shows. Thereby reduced vibrations and knocking noises when the rotor touches on the motor case are seen (in the upper graph of Fig. 13).

Realized by these technical measures is the more user-friendly electric utility three-wheeler featuring the quietness, lower vibrations, and the higher driving performance.

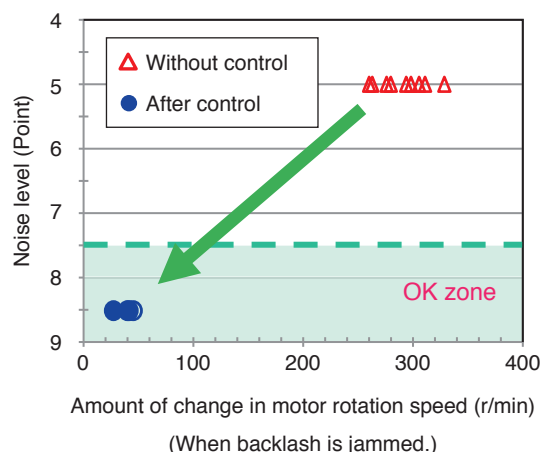


Fig. 14 Countermeasure effect in control

5. Conclusion

- (1) With the electric powertrain developed presuming application to the non-tilting cargo carrier having higher hurdles, the two types of three-wheelers have been developed to meet various demands of cargo carrying while using a common electric powertrain.
- (2) Applying the same battery mounting system as BENLY e: which allows locating of the batteries, which affects largely to the CG height, at a low part of the vehicle, and incorporating the reverse assist, the electric three-wheelers featuring easier handling than the gasoline engine three-wheeler have been realized.
- (3) By the change from the belt-driven CVT to the clutchless gear drive along with the newly developed torque controller to take up free play to control vibrations and knocking noises, the driving performance higher than the gasoline engine three-wheeler has been achieved while keeping the noises and vibrations at a low level.

The sales of GYRO e: for corporate users started from March 2021 and GYRO CANOPY e: from October 2021. The users who have actually used it perceive advancement and comment positively. The utility electric scooters such as the BENLY e: offered to the market from January 2020 are

seen more frequently now. We would like to hear customers saying “I bought a good scooter. It turned out electric.” especially in these days the electrification is drawing attention. We anticipate these electric three-wheelers serving as a pioneer.

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