

# Development of Electric Trials Motorcycles

## RTL ELECTRIC

Akio SAITO<sup>1</sup>

Hiroyuki AKIYOSHI<sup>1</sup>

Masayuki KINOSHITA<sup>1</sup>

Yusuke FUKAO<sup>1</sup>

Naoki ISHII<sup>1</sup>

Takuya FURUYAMA<sup>1</sup>

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### ABSTRACT

While the widespread adoption of electric motorcycles is needed to achieve carbon neutrality, their appeal and value have not yet been fully communicated. We therefore focused on the use of electric vehicles for trial racing as a way to demonstrate their value. Trial racing is a sport that requires not only low-speed torque and high-power output but also precise control, making it an ideal arena for leveraging the characteristics of electric vehicles.

Using an ICE vehicle (RTL301RR) as a benchmark, we developed the Electric Trials Motorcycles RTL ELECTRIC with the goals of achieving power characteristics that balance high torque at low speeds with high power output at high speeds, providing drivability that meets rider requirements, and optimizing the center of gravity. In developing electric vehicles, we introduced technologies unique to electric vehicles, such as a transmission mechanism tailored to torque characteristics, torque control based on the rider's feel, and an optimized component layout. As a result, we achieved multiple victories in the 2024 All-Japan Trial Championship and the Trial 2 class of the 2025 World Championship.

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## 1. Introduction

One initiative aimed at achieving carbon neutrality is the widespread adoption of electric motorcycles. To this end, it is necessary to create value in electric vehicles to differentiate them from internal combustion engines (ICE) and to establish that value in the market.

The torque characteristics of electric vehicles enable precise torque control that cannot be achieved with internal combustion engines. By leveraging the advantages of electric power, it becomes possible to achieve a driving experience that was not possible with ICE vehicles, and this is expected to contribute to the evolution of trial racing itself. Furthermore, since trial races feature a mix of ICE and electric vehicles, an electric vehicle's victory over an ICE vehicle is expected to have a significant impact on raising widespread awareness of the benefits of electric power.

Against this backdrop, we developed a vehicle designed to meet the key requirement of the capability to win races, and it achieved victories in numerous competitions.

This paper introduces the electric drive technology and complete vehicle technology that comprise the electric trial vehicle RTL ELECTRIC shown in Fig. 1<sup>(1)</sup>.



Fig. 1 External view of RTL ELECTRIC

## 2. Trial Racing and Vehicles

### 2.1. Characteristics of Trial Racing

In off-road trial racing, the competition focuses on vehicle handling skills rather than speed. As shown in Fig. 2, riders navigate a taped-off course known as a “section” on vehicles specifically designed for trial racing.

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<sup>1</sup> Honda Motor Co., Ltd.

E-mail: akio\_saito@jp.honda

A section consists of turns combined with obstacles and slopes that make use of natural or artificial terrain. Riders must complete such a section without putting a foot down. Putting a foot down results in a one-point penalty, and these penalties accumulate. A race consists of 10 to 12 sections, and the rider with the fewest total penalty points after completing all sections is declared the winner. Under the rules effective from 2025 onward, two races are held each day, and points are awarded independently for each race to determine overall standings.

## 2.2. Characteristics of Trials Motorcycles

As shown in Fig. 3, sections include obstacles taller than a person and wall-like steep slopes. To overcome them, vehicles require high driving force at high engine speeds and a large inertial mass.

In addition to these requirements, when vehicles accelerate rapidly from a loaded state on inclines or steps, high driving force in the low-speed ranges is required and, on slippery road surfaces, the torque characteristics should respond linearly to throttle input. Furthermore, since greater vehicle weight hinders control when balance is lost, vehicle weight has been minimized to the absolute limit. Furthermore, consideration has been given to the shape of the various exterior components that does not hinder the rider's movements on the vehicle and the shape of the



Fig. 2 Trial section



Fig. 3 Rocks and hills in trial section

vehicle's underbody that minimizes interference when clearing obstacles. In terms of vehicle motion, maneuvers, such as lifting the front wheel as shown in Fig. 4<sup>(1)</sup>, are common, and it is important that such pitching motion be easy to control. One such factor is the vehicle's center of gravity, and its position affects how easily the pitching motion described above can be controlled. In particular, since trial vehicle operation involves the rider shifting the weight forward and backward primarily around the footpegs, care is taken to position the vehicle's center of gravity close to the rider's footpeg position.

## 2.3. Current Status of ICE Trials Motorcycles

### 2.3.1. Achieving Both Low-Speed and High-Speed Driving Performances

As mentioned above, trials motorcycles require high driving force in both the low-speed and high-speed ranges. For ICE vehicles, especially in the frequently used range at or below idle speed, reducing the engine speed too much can cause the engine to stall. Therefore, riders need to operate the clutch and throttle while being aware of fluctuations in engine speed to avoid entering the stalling range. Within this engine range, significant driving force is required to control the vehicles in the low-speed range under high load. ICE vehicles meet this requirement by modifying the output characteristics through changes to the specifications of the engine and intake/exhaust components, as well as by increasing the gear ratio. However, such modifications reduce engine output at high engine speeds. This is because ICEs utilize gas inertia and pulsation effects, resulting in power output that peaks at specific engine speeds. Consequently, it is not easy for ICEs to achieve both low- and high-speed power output simultaneously, and this is typically addressed by increasing engine displacement to boost overall power or by using multispeed transmissions. However, since these measures tend to make the vehicle larger and heavier, the vehicle is typically designed with well-balanced power characteristics and gear ratios, while any remaining shortfalls are compensated for by the rider's throttle control skills.



Fig. 4 Front wheel lifted situation

### 2.3.2. Requirements for Drivability

In trials, it is required that the linearity of torque in response to the rider's throttle input, the torque response to sudden throttle opening<sup>(2)</sup>, and the torque delivery in response to road load all meet the rider's expectations. To this end, the output torque in response to the rider's throttle input needs to be set appropriately. In ICEs, torque is generated indirectly from the physical phenomenon of combustion, which makes the outcome difficult to predict. To set the torque as intended, all parameters affecting output, including intake and exhaust specifications, fuel injection volume, ignition timing, and environmental compensation settings, need to be appropriately configured. Since achieving this is not easy, adjustments are made through trial and error so that any final discrepancies are compensated for by the rider's skill.

### 2.3.3. Vehicle's Position of Center of Gravity

As mentioned above, to improve pitch controllability, it is desirable to position the center of gravity closer to the rider's footpeg position. In ICE vehicles, there is little flexibility in component layout because the layout of the crankshaft and pistons, the arrangement of cooling system components, the diameters and lengths of the intake and exhaust passages, and the position of the fuel injection system all directly affect output performance. Because of the placement of the crankshaft, cooling system, and fuel system components, the front end tends to be heavier, and the center of gravity is located toward the front relative to the rider's footpegs. To address this issue, changing the position of the fuel tank is effective. However, doing so may make it difficult to satisfy the required intake and exhaust specifications because of layout constraints, potentially compromising output performance. Therefore, the vehicle's center of gravity is adjusted by selecting a layout while taking rider requirements into account.

## 3. Development Using the Advantages of Electric Vehicles

### 3.1. Development Goals

In light of the current state of ICE vehicles described above, we established the following four development goals to achieve race-winning performance by using the advantages of electric vehicles. The development target values were set using RTL301RR<sup>(3)</sup> manufactured by Honda Racing Corporation (HRC), which is equipped with a four-stroke engine as the benchmark.

- (1) The maximum power output required to complete trial sections needs to be sustainable until the battery changes during the race.
- (2) The vehicles need to have rear-wheel driving force equal to or greater than that of the RTL301RR in both the low- and high-speed ranges.
- (3) The vehicles need to satisfy the rider's requirements for drivability.

- (4) Compared to the RTL301RR, the center of gravity needs to be closer to the rider's riding position.

### 3.2. Challenges in Achieving the Goals

#### 3.2.1. Sustainability of Maximum Output

In electric vehicles, the battery is a key factor in determining power output. Batteries are characterized by their capability to instantaneously deliver stored energy at high power. However, since the batteries consume energy, the state of charge (SOC) decreases, reducing the maximum power that can be delivered instantaneously. In other words, the maximum power output decreases with decreasing SOC. Since riders dislike changes in performance, this is a challenge unique to electric vehicles. Therefore, it is necessary not only to set the maximum power output to the minimum level required to complete trial sections but also to account for energy consumption during the race and to determine the battery capacity so that this maximum power output can be maintained even as the SOC decreases.

#### 3.2.2. Achieving Rear-Wheel Driving Force in Both Low- and High-Speed Ranges

Most electric vehicles do not have a transmission, taking advantage of their wide torque band. However, since trials motorcycles need to perform low-speed, high-load acceleration and climb high-speed, high-load uphill sections, high rear-wheel driving force is required in both the low- and high-speed ranges. Achieving this with a single gear requires a larger motor and battery, resulting in increased vehicle weight. Therefore, a transmission needs to be employed and set to an appropriate gear ratio that matches the power characteristics.

#### 3.2.3. Drivability Settings

Drivability is determined by how torque is delivered in response to throttle input. In electric vehicles, the output torque value can be set directly. Therefore, everything from large torque changes that require hardware modifications in ICE vehicles to fine adjustments for meeting rider requirements can be achieved solely through software setting changes. Since there are no hardware limitations on torque characteristic settings, which is the case with ICE vehicles, it has the potential to achieve drivability that was not possible with ICE vehicles. However, to approach this target, it is necessary to explore torque settings in areas where no prior knowledge exists by relying on the rider's feel.

#### 3.2.4. Vehicle's Center of Gravity and Layout

To improve pitch control, the center of gravity needs to be shifted closer to the rider's riding position. When modifying the component layout, the vehicle should retain a proven trial-vehicle shape that does not restrict the rider's range of motion while ensuring that obstacle-clearing capability and rough-terrain performance are not adversely affected. For elements that affect these performance aspects,

including minimum ground clearance and rear fender shape, the geometry of each component needs to be determined so as to follow the basic specifications of the RTL301RR.

## 4. Electric Technology for Solving Challenges

### 4.1. Battery Capable of Sustaining the Required Maximum Power Output

To ensure that the maximum power output required to complete trial sections is supplied consistently, the required maximum power output and battery capacity were specified.

#### 4.1.1. Required Maximum Power Output

One situation in trial racing that requires the highest power output is a hill-climbing section. To complete this section, sufficient rear-wheel driving force and vehicle speed are required to climb a steep slope. Figure 5 shows the RTL301RR's driving data in the most challenging hill-climbing section.

Before beginning acceleration, the throttle is opened with the clutch disengaged to increase Ne (number of engine revolutions). After that, the clutch is engaged to begin acceleration, and the vehicle speed increases. The vehicle climbs the hill while the rider modulates the throttle to clear obstacles. Since wheelspin occurs when the vehicle clears obstacles or uneven road surfaces, the vehicle speed shown in the graph fluctuates sharply. However, in reality, it continues to accelerate while climbing the hill. The absence of a further increase in vehicle speed as shown in the graph indicates that the maximum gradient in this hill-climbing section corresponds to the region highlighted in yellow in Fig. 5. Beyond the region highlighted in yellow in Fig. 5, the gradient becomes gentler. However, the vehicle speed decreases, and frequent throttle modulation occurs for clearing obstacles.

Focusing on the yellow-highlighted region, it can be observed that although the throttle opening is at 100%, neither Ne nor vehicle speed shows an upward trend. In other words, this is the point at which the load from the road surface is greatest and is balanced by the rear-wheel driving force. Therefore, the power output at this point is the maximum power output required for a trial vehicle.

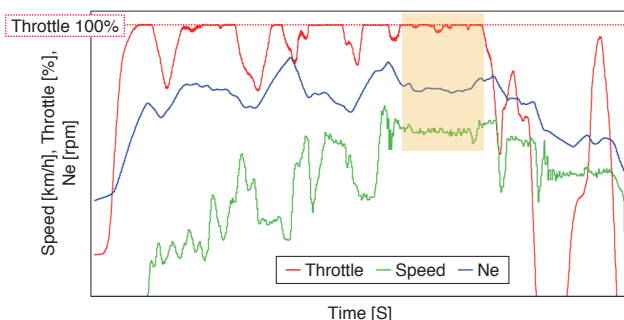


Fig. 5 Hill climbing log data

### 4.1.2. Battery Capacity

It is necessary to estimate the battery capacity required to maintain the maximum power output mentioned above. Since regulations allow for battery replacement upon returning to the paddock, a target value can be set if the maximum energy consumed per lap can be calculated. At this point, the required battery capacity is not simply the capacity required for maximum consumption. In addition, as mentioned in Section 3.2.1, it needs to also include the capacity necessary to maintain maximum power output even after the SOC has decreased.

In trials, riders proceed from the start through each section and the liaison between sections, returning to the paddock after completing 10 sections. This is one lap, and a race consists of two laps. Since energy consumption can be calculated by integrating power over time, this integration was performed using the driving log data and power-output characteristics of the RTL301RR, an ICE vehicle. The results obtained by applying the same integration to all race laps are shown in Fig. 6. The red line indicates the lap with the highest energy consumption among all race laps.

The results of determining the required battery capacity using this maximum consumption are shown in Fig. 7. The

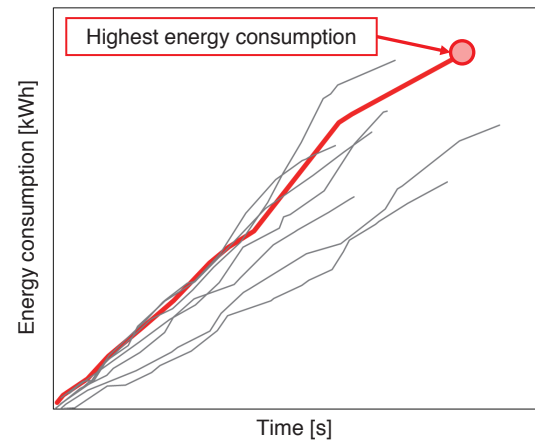


Fig. 6 Energy consumption per lap for entire race

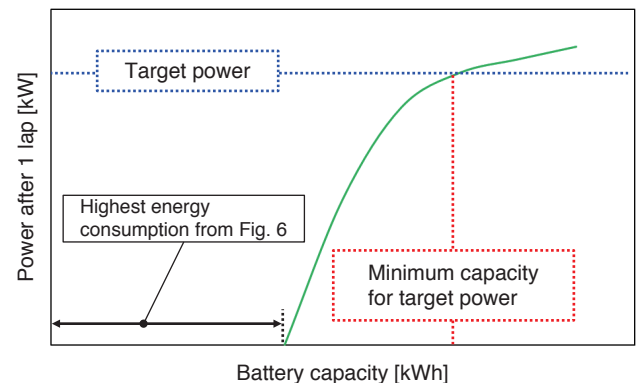


Fig. 7 Minimum battery capacity for target power

horizontal axis represents battery capacity, the vertical axis represents power output, and the solid green line indicates the maximum power output that the battery can deliver after the one-lap energy consumption described above. As the capacity increases, the available output also increases, and the point at which the curve intersects the required power output represents the minimum necessary capacity. As a result, when taking into account the power output during SOC decline, it was found that approximately twice the capacity determined in Fig. 6 was required. Based on this, a battery capacity was determined that balances capacity margin against weight.

#### 4.2. Achieving Both Low- and High-Speed Rear-Wheel Driving Force

This section describes the gear ratio settings required to achieve high rear-wheel driving force in both low- and high-speed ranges, as well as the powertrain structure designed to accommodate these settings compactly within a trial vehicle.

##### 4.2.1. Gear Ratio

Fig. 8 shows the torque curves for the RTL301RR and the RTL ELECTRIC. Although the ICE has slightly higher torque in the mid-speed range, the electric motor offers advantages in the other speed ranges. The required performance for a trial vehicle includes both low-speed controllability and high-speed, high-power performance for climbing steep slopes. Therefore, taking into account the torque characteristics of the electric motor, a transmission for this model was specified to meet the required rear-wheel driving force characteristics. Figure 9 shows the rear-wheel driving force diagram for the RTL301RR and the RTL ELECTRIC.

Although the electric vehicle's first gear has a gear ratio equivalent to the ICE vehicle's second gear, the electric vehicle provides greater driving force in the low-speed range. Therefore, the ICE vehicle's first gear is

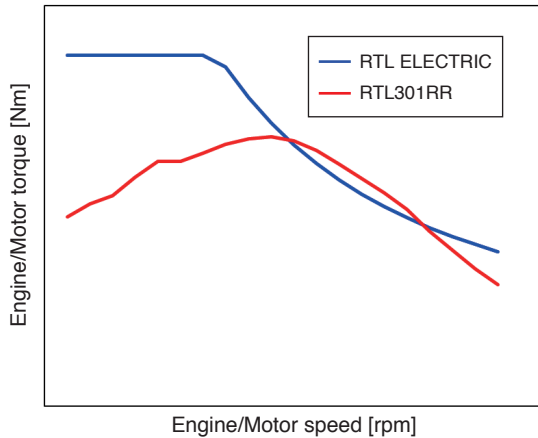


Fig. 8 Torque curve comparison between EV and ICE

considered unnecessary for the electric vehicle. In this way, by leveraging the motor's high torque, it is possible to cover a wide driving-force range with fewer gear stages, contributing to a smaller and lighter transmission.

##### 4.2.2. Powertrain Configuration

Although the size of the electric motor is determined by the required power output and torque, its outer diameter tends to be larger than that of the crankshaft of an ICE in the same power range. For this reason, when positioning a transmission, it is necessary to maintain a large distance from the motor. If the required primary reduction ratio is designed with a single gear pair, the driven gear has an excessively large outer diameter, making it unlikely to meet the vehicle's space constraints. Therefore, as shown in Fig. 10, this model specifies an idle gear shaft midway through the primary reduction to limit the increase in gear diameter. In addition, the idle shaft was supported in a cantilever configuration rather than at both ends, providing space between the idle gear and the motor. A flywheel was then positioned in that space to achieve mass centralization.

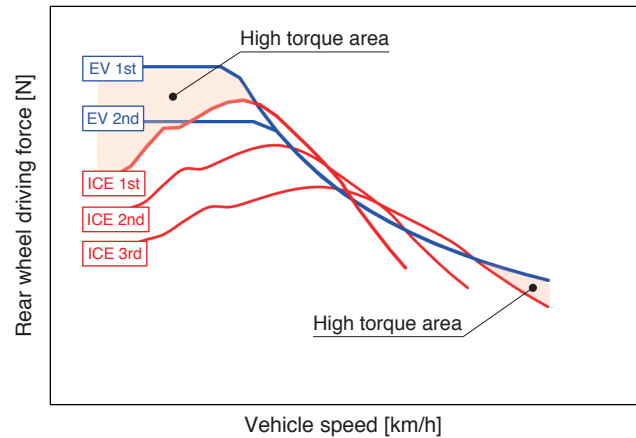


Fig. 9 Driving force diagram

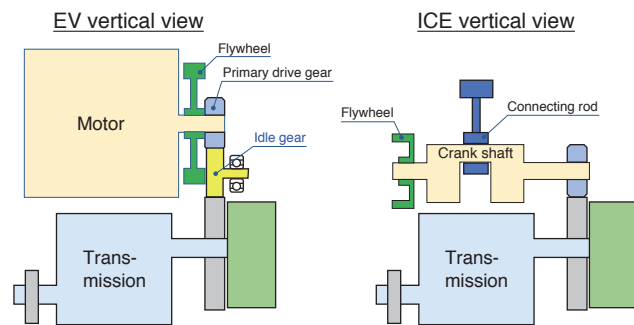


Fig. 10 Comparison of electric and ICE drivetrain systems

#### 4.3. Torque Control to Meet Drivability Requirements

For trial-vehicle drivability, acceleration and deceleration torque needs to be generated as intended in response to throttle input. Since the load conditions on the road surfaces traveled by trials motorcycles change moment by moment because of unevenness, mud, and other factors, riders sense the sounds, vibrations, and acceleration transmitted from the vehicle, instantly predict how the vehicle will behave in response to throttle input, and use it to determine their next operation. In particular, fluctuations in engine speed when the tires are subjected to load from the road surface provide important information. Therefore, it is necessary to set the torque appropriately, taking into account not only acceleration and deceleration but also the need to convey the tires' grip conditions on the road surface to the rider.

##### 4.3.1. Acceleration and Deceleration Torque Setting

The acceleration and deceleration torque settings use a map-based method in which torque values are set for each throttle opening at each motor speed. Since there were no clear target values for these settings, initial testing used maps that simulated the torque characteristics of the RTL301RR as well as linear maps that set torque linearly to throttle opening at each speed. The maps were verified and compared while differences in vehicle behavior caused by each map are observed, including riders' subjective evaluations. As a result, a map suitable for trials was finalized as shown in Fig. 11.

The regions of the map corresponding to throttle-opening situations that are important in trials are shown as (1) through (3) in Fig. 11. Region (1) affects the kick feel that indicates an abrupt torque response at the very beginning of the throttle opening in the low-speed ranges. Region (2) affects the driving force during situations involving rapid acceleration from a loaded state on inclines

or steps. To explain regions (1) and (2), the torque axis that accounts for the change in  $N_e$  during rapid throttle opening is shown by line (4) in Fig. 11. The results of plotting the relationship between throttle opening and torque along line (4) are shown in Fig. 12. For comparison, a map in which torque increases linearly with the throttle opening and a map simulating ICE characteristics are also shown. For the RTL ELECTRIC, the torque is set to provide a kick feel similar to that of ICEs at low throttle openings while, at high throttle openings, it utilizes the high torque unique to electric motors to enable acceleration even under heavy loads.

Next, Region (3) in Fig. 11 requires a characteristic in which, during acceleration at a fixed throttle opening, the power output continues to increase as the motor speed rises without giving the rider the sensation of hitting a power limit. As an example, Figure 13 shows the relationship between the motor speed and the power output at an 80% throttle opening. The RTL ELECTRIC is configured so that the power output increases steadily from low to high speeds,

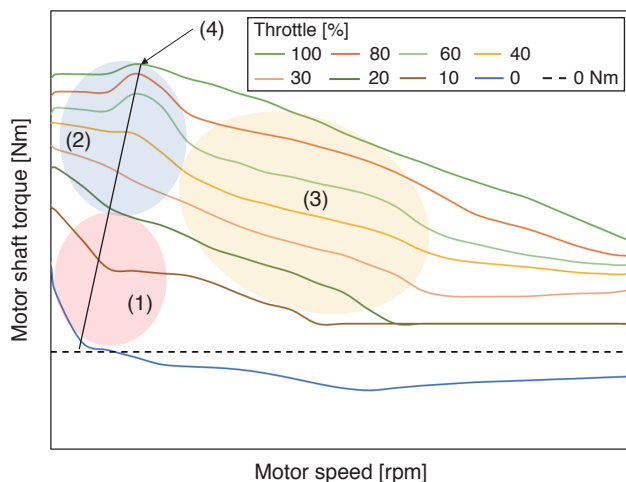


Fig. 11 Mapping of RTL ELECTRIC

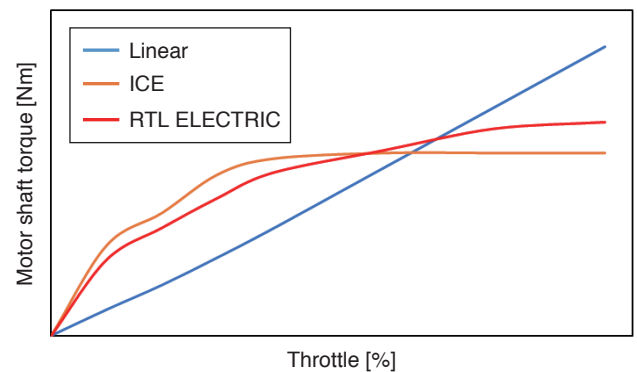


Fig. 12 Torque characteristics during rapid throttle opening

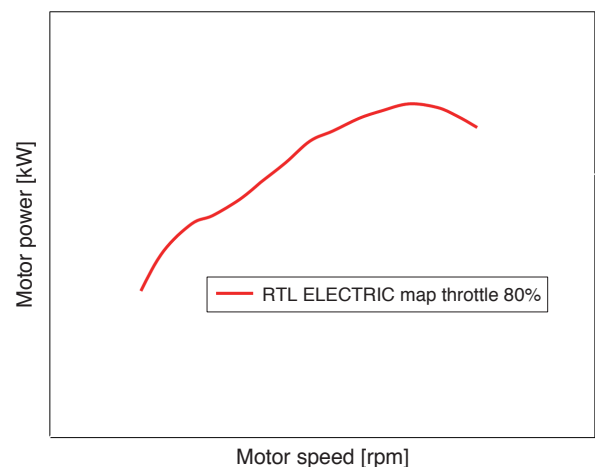


Fig. 13 Power curve RTL ELECTRIC

allowing the rider to feel an increase in power output as the speed increases, without giving the rider the sensation of hitting a power limit.

#### 4.3.2. Rider Information

As mentioned above, riders sense torque delivery from fluctuations in motor speed caused by road loads acting on the tires and adjust the throttle opening accordingly. This allows them to achieve maximum acceleration without causing excessive rear-wheel slip. In addition, riders sense whether or not the tire is slipping from the rate of increase in motor speed when the driving force is transmitted to the road surface. If the rate of increase in motor speed is too high, the vehicle feels prone to slipping and difficult to control. If it is too low, the vehicle feels less prone to slipping and easier to control, but sufficient acceleration cannot be achieved. When the vehicle's driving force and motor-speed fluctuations under road-load conditions align with the rider's expectations, both controllability and sufficient acceleration are achieved. Riders often commented that they have a "torque feel," "grip feel," or "tractability."

As an interesting example, a rider who was unable to complete a hill-climbing section commented that the vehicle had little torque feel and felt weak. In this case, the settings were adjusted in the direction of reducing torque rather than increasing it. Then, the rider was able to complete the hill-climbing section and commented that there was a torque feel. As this example shows, the relationship between the magnitude of the torque value and the intensity of the torque felt by riders may not always correspond. By incorporating such expertise into the setup, we achieved a balance between ease of handling for riders and sufficient acceleration.

#### 4.3.3. Power Output Switching Control Linked to Clutch Operation

One aspect of drivability that cannot be adequately addressed by torque settings alone is torque control during idling. In the RTL ELECTRIC, torque is generated even when the throttle is fully closed, similar to the idling of an ICE vehicle. Since this idling torque can supply stable torque without throttle input, it is used to keep the front tire off the ground or to move the vehicle forward from a stationary position on slippery road surfaces.

Regarding this idling, while high torque is required to move the vehicle forward on an uphill slope, there is also a need to keep the motor speed low to help prevent rear-wheel slip when the clutch is engaged. However, when the torque setting required for starting is high, the motor speed rises more than necessary in the disengaged clutch state (under no-load conditions) due to low motor friction, making it challenging to meet the requirement to suppress the speed.

To address this issue, a function was implemented to switch torque settings via clutch operation. A setting with reduced torque is prepared for no-load conditions and a

setting with increased torque for loaded conditions, and they are switched via clutch operation. This feature made it possible to meet the rider's needs under both loaded and unloaded conditions.

#### 4.3.4. Torque Response Correction Control

While the electric vehicle's rapid response to requests for increased or decreased output is a major advantage over ICE vehicles, a slight delay in response to throttle operation often makes the vehicles easier for riders to handle. Rather than applying the requested torque from throttle input directly as driving force, control was added to delay the torque response for both throttle-on and throttle-off inputs, resulting in a more natural acceleration and deceleration feel. In particular, reproducing the delay that occurs in ICE vehicles during throttle-off operation was found to contribute to ensuring vehicle controllability in trials.

### 5. Complete Vehicle Technology Leveraging Freedom in Component Layout

#### 5.1. Component Layout and Position of Center of Gravity

As mentioned above, ICE vehicles have limited flexibility in component layout, whereas electric vehicles offer a high degree of flexibility. Taking advantage of this flexibility, the components were arranged as shown in Fig. 14 in order to shift the vehicle's center of gravity, which was a key factor in vehicle handling performance, closer to the rider's riding position. As a result, compared to the RTL301RR, the vehicle's center of gravity was positioned 12.5 mm closer to the rider's riding position.

The feature is that the motor, which is the heaviest component, is positioned close to the rider's riding position. This layout is advantageous not only in its current form but also because, as batteries become lighter and more compact in the future, it will allow the center of gravity to be moved even closer to the rider's riding position, thereby improving dynamic performance without requiring major changes to the component layout.

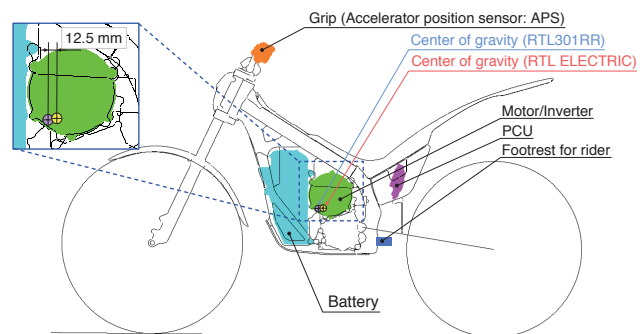


Fig. 14 Position of center of gravity

## 5.2 Layout Ensuring Battery Protection and Capability to Clear Obstacles when in Contact

The battery protection structure is shown in Fig. 15. One drawback of the component layout, which prioritized vehicle dynamic performance, was the risk of the battery, which is located on the vehicle's underside, coming into contact with obstacles when clearing them. To protect the battery, down tubes were routed on both sides, and the underside of the battery was covered with a skid plate, creating a structure that helps prevent damage to the battery. Furthermore, to provide protection for the battery even if the skid plate were to deform, the down tubes were designed to restrict the deformation of the skid plate. As a result, the skid plate is larger than that of an ICE vehicle, making it more likely to come into contact with obstacles.

Therefore, as shown in Fig. 16, the angle  $\theta$  and bending radius  $R$  of the skid plate were specified so that the vehicle could clear obstacles with as little loss of speed as possible upon contact. The forward inclination angle ( $\theta$ ) of the skid plate is an angle that minimizes the loss of speed upon contact with obstacles from the front. This angle was set to be the same as that of the RTL301RR. In addition, the bending radius ( $R$ ) of the skid plate was set to be equal to or greater than that of the RTL301RR, improving the vehicle's capability to clear obstacles. As a result, the vehicle's

capability to clear obstacles upon contact is now equivalent to that of the RTL301RR.

## 5.3. Frame Structure

The frame structure is a twin-tube frame, similar to that of the RTL301RR, achieving a configuration that provides the rigidity and strength required for trials motorcycles. Furthermore, as shown in Fig. 17, to allow the frame rigidity to be adjusted according to the rider's preferences, the cross pipe positioned between the main pipes was designed as a bolted structure separate from the frame body.

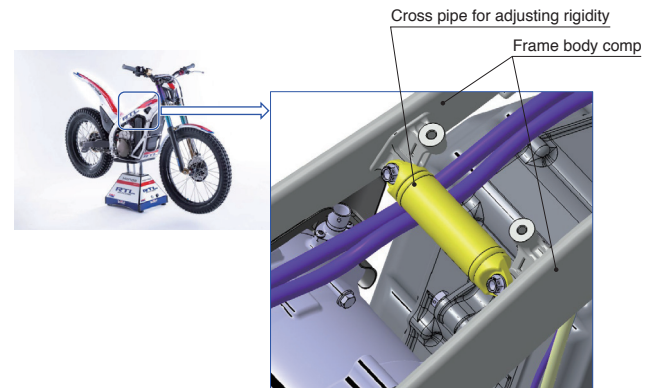


Fig. 17 Structure to adjust frame stiffness

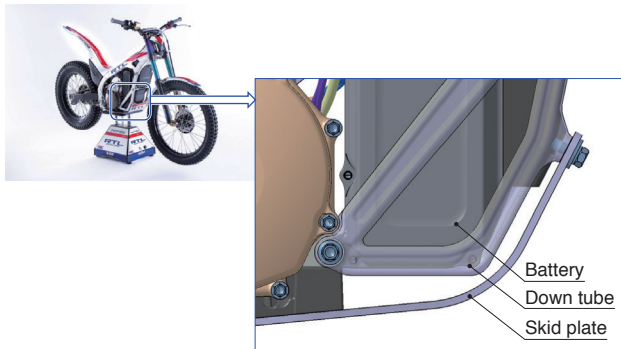


Fig. 15 Structure for battery protection

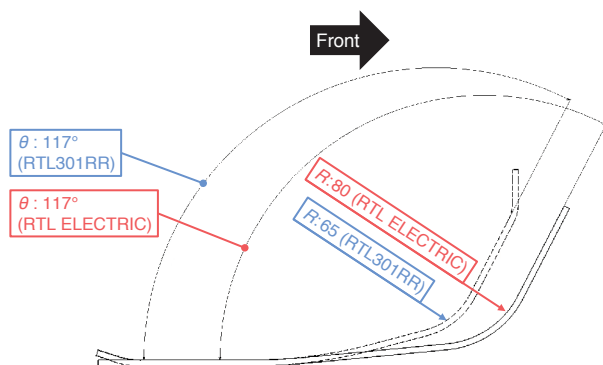


Fig. 16 Comparison of skid plate shapes

## 6. Race Results

As part of the RTL ELECTRIC race evaluation program, the vehicle competed in races in 2024 and 2025. In 2024, the RTL ELECTRIC was entered on a spot-entry basis in the International A-Class Super Class, the top category of the All-Japan Trial Championship, and won all races it entered from Rounds 6 to 8<sup>(4)</sup>. In 2025, the RTL ELECTRIC competed throughout the season in the Trial 2 class, the second-highest class in the World Championship. Although we finished second in the season standings and missed out on the championship title, we recorded the highest number of wins in the class with five victories<sup>(5)</sup>.

## 7. Summary

By incorporating the technical achievements outlined below, we developed the RTL ELECTRIC, an electric trial vehicle capable of competing on equal footing or even outperforming ICE vehicles in races.

- (1) We successfully built an electric power unit that delivers both the low-speed and high-speed driving force required for trials motorcycles.
- (2) By combining torque map settings, output switching control linked to clutch operation, and torque response correction control functions, we were able to develop

torque control that met riders' drivability requirements.

- (3) Thanks to the component layout unique to electric vehicles, we were able to shift the center of gravity 12.5 mm closer to the rider's riding position compared to the RTL301RR.
- (4) The skid plate provided battery protection while maintaining obstacle-clearing capability at a level equivalent to that of the RTL301RR.

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## ■ Author ■



Akio SAITO



Masayuki KINOSHITA



Naoki ISHII



Hiroyuki AKIYOSHI



Yusuke FUKAO



Takuya FURUYAMA