

Development of Electric Motocrosser CR ELECTRIC

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ABSTRACT

In an attempt to offer a new value of EV in the FUN category such as the motorsports, the electric motocrosser CR ELECTRIC has been developed. The employment of launch control and energy management systems upon the selection and control of battery cells enabled realization of the dynamic performance and the range required for the motocross machine. Developing the L-shape battery pack and optimizing the frame body stiffness, the specification of complete vehicle similar to the CRF450R are achieved. Moreover, the development of high-voltage pack as high as 400 volt along with the redesigning of the cooling system to adjust to the electric motocrosser resulted in the downsizing and weight reduction of various component parts. With these measures taken, the maneuverability and stability such as nimbleness, roadability, and turnability have been accomplished.

1. Introduction

The changes of social environment call for realization of carbon neutralization not only in automobiles but also in motorcycles. Honda aims at a carbon neutralization in all products and all corporate activities by 2050. It is Honda's policy to achieve carbon neutrality in all motorcycle products in the 2040s. As a core environmental strategy to achieve the said goal, we are actively promoting electrification of motorcycles⁽¹⁾.

In the realization of carbon neutrality in the mobility sector, even the motorsports are not exceptional. In the Formula 1 and MotoGP, introduction of carbon-neutral fuel has already started^{(2), (3)}. Regarding the electrification, races exclusively for electric vehicles (EVs) such as the Formula E and MotoE are being held. However, the energy density of lithium-ion battery is approximately 2% of that of gasoline, which is an issue in races requiring frequent use of high-power output. Meanwhile in EVs, the power output is easy to control due to the recent advancement of motor control techniques, having easy-to-control drive-ability. In addition, as the EV is quiet and clean without emissions of exhaust gas, it is an advantage that races can be held in urban cities and in-door arenas.

Honda has offered electric motorcycles to the market as small commuter motorbikes for use in short distances such as delivery and/or means of day-to-day transportation. Adding to the said applications as a creation of new value in FUN category, we have developed the electric motocrosser with a focus on motocross races, which are popular in Europe and

North America, and also held in stadiums and the likes.

As a technical validation, the EV motocrosser was raced in the Kawagoe round, the 8th race of 2023 Japan Championship Motocross Series. The results were very positive; 2nd place in Heat 1, and two hole-shots in three heat races. That attracted media attention as Honda's first race participation with the electric motorcycle, resulting in a recognition of EV.

In this paper, we introduce the technical measures employed in the electric drive unit such as the battery, which is an essential part in the electric motocrosser CR ELECTRIC shown in Fig. 1, and the chassis techniques to package such parts.



Fig. 1 External view of CR ELECTRIC

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2. Aims of Development

2.1. Features of Motocross

The motocross is such a sprint race that contests speed in unpaved, short race courses. Various places such as outdoor flat lands and hills or stadiums are used as the field. The race course has manually-created ups and downs. As Fig. 2 shows⁽⁴⁾, some big jumping spots are included to demonstrate three-dimensional actions such as jumping and landing. As the track conditions varies depending on the weather or repetition of races, the vehicle has to deal with a variety of elements.

The race program is such that a heat race lasting from 15 minutes to 30 minutes is held two to three times a day. Base on the results of heat races, a final race is held for overall ranking. With thirty to forty machines line up side by side and all dash out together from the starting gate, the spectacular start scene is one of its charms.

In motocross races held under such conditions, the compactness of vehicle body and the lightness of weight are the keys. A bulky and heavy motocrosser is difficult to ride no matter how powerful the motor is. To travel on slippery off-road surfaces, linear torque delivery and easy-to-handle traction performance are essential although a high maximum power is also important⁽⁵⁾.

Due to the race style in that a large number of racers start together, a hole shot (to be the first one to enter turn 1 after starting) is very advantageous to win the race or finish higher.

2.2. Features of EV

2.2.1. Installed energy

The internal combustion engine (hereafter ICE) converts the thermal energy occurring from combustion of gasoline to the mechanical energy to produce driving force. Meanwhile in EVs, the motor converts the electric energy in the battery to the mechanical energy to produce driving force. In current battery technology, the energy density per weight is approximately 2% of that of gasoline. Even if the higher driving force conversion efficiency of electric motor is taken into account, the available energy is approximately 40% of



Fig. 2 Motocross riders jumping on track

that of an ICE vehicle in the same class. These characteristics result in the short range and heavy vehicle weight of Evs.

While the gasoline-burning ICE loses much energy as waste heat, the electric power conversion efficiency is higher in Evs, and the waste heat is not as much as in the ICE. On the other hand, the battery changes characteristics depending on the temperature. For efficient use of limited energy on the vehicle, it is essential to adjust heat management to the operating conditions and working environment.

2.2.2. Output characteristics

Figure 3 shows driving force diagrams of EV and internal combustion engine vehicle (ICEV). In the EV, a high torque is attainable at lower revolutions due to the characteristics of the battery and the motor. The torque and the power output occurring from the electricity can be easily modified by the control program. This feature is different from the ICE in that an adequate torque is unattainable until the engine speed reaches to a certain level.

Figure 4 shows difference of power output characteristics in EV and ICEV. While an appropriate gear has to be used in the ICEV depending on the vehicle speed to maintain a higher power output, a flat power output up to higher revolutions is attainable in the EV without changing the gear.

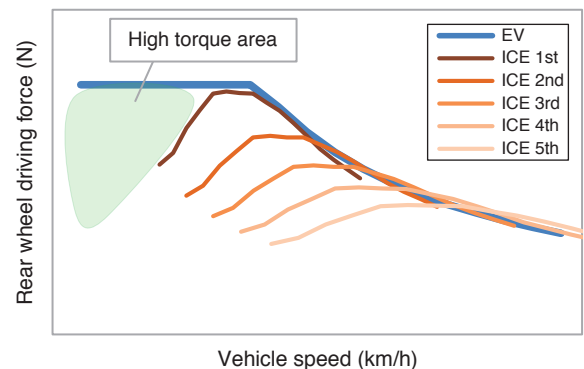


Fig. 3 Comparison of driving force between EV and ICEV

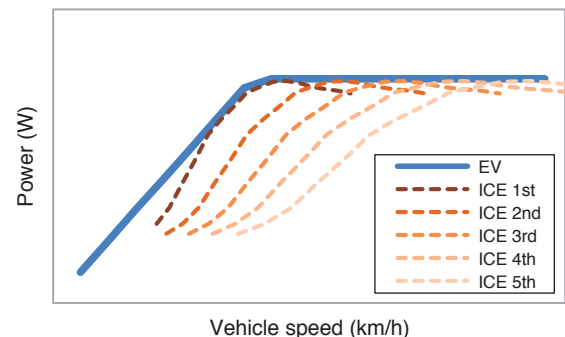


Fig. 4 Comparison of power characteristics between EV and ICEV

Table 1 Specifications of 2021 model CRF450R

Overall length [mm]	2182
Overall width [mm]	827
Overall height [mm]	1267
Ground clearance [mm]	336
Seat height [mm]	965
Caster angle [deg]	27.7
Trail [mm]	114
Wheelbase [mm]	1481
Front brake	Single 260 mm disk
Rear brake	Single 240 mm disk
Front suspension	49 mm fork
Rear suspension	Pro Link
Front tire	80/100-21 51 M
Rear tire	120/80-19 63 M

In other words, the maximum speed is easily reachable only by the throttle operation. It is therefore not necessary to select an appropriate gear depending on the speed, allowing easy control of the vehicle only by a simple operation, which is a feature that makes the vehicle user friendly.

2.3. Development Goals

The power output characteristics of EV mentioned in the preceding chapter can be considered an advantage in the motocross competition where the course conditions keep changing. To take that advantage, the machine has to have the power output and range comparable to the ICEV. We therefore set such goals that the machine has the same level of power as the CRF450R and able to finish a heat race that lasts for 15 minutes. Also, the key factors in the race are turnability and off-road-ability, which are affected by the location of center of gravity (CG) and the frame stiffness of the complete vehicle. We targeted at the specifications of complete vehicle similar to those of the CRF450R as Table 1 shows also in the EV carrying different component parts.

2.4. Issues of EV in Motocross

As Fig. 5 shows, due to the difference of installed energy when the complete vehicle specifications required for the motocrosser are compared, if the installed energy in the EV is simply equalized to the ICEV, the vehicle body becomes bulky and heavy. If a higher power output is continuously used from the limited amount of installed energy, the target range is unattainable. It is therefore necessary to work out a way to extend range while maintaining a higher power output taking advantages of the characteristics of EV. Also, as the energy for use differs, the component parts also differ. Since it is not easy to commonly use conventional parts simply, the major components such as the frame body have to be modified, which is also an issue.

There is also an issue of heat from electric components.

In the EV, the power loss that occurs when the power is supplied to drive the motor is converted to the thermal energy, which generates heat. The major components of EV, i.e., the motor, battery, and inverter, generate heat when electric power is supplied. Since such parts may be damaged when the temperature exceeds the limit, a function is incorporated to limit the power output to maintain the temperature under the prescribed level. As the lowering of acceleration and/or torque from the limiting of power negatively affect motocross race performance, a proper thermal management of electric powertrain parts is required.

Introduced from the next chapter on is the elemental techniques employed in this paper to deal with the issues in the EV motocrosser.

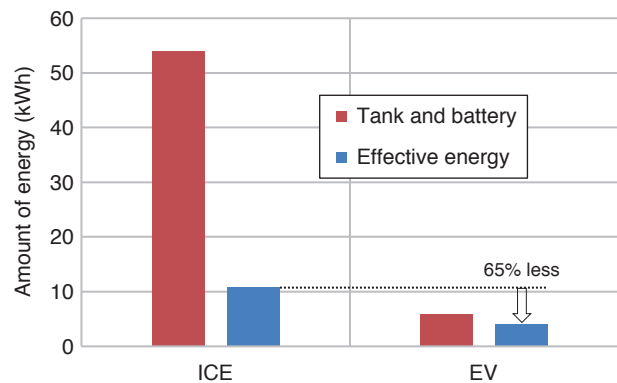


Fig. 5 Comparison of installed energy in motocrossers of EV and ICE

3. Elemental Techniques for EV

3.1. Battery

The battery is a critical part when determining performance and specifications of the complete EV. Described hereafter are the construction of the battery pack (hereafter “pack”) and its system that can be smallest and lightest when realizing the necessary power output and range required by the complete vehicle.

3.1.1. Battery pack construction

The pack is composed of a number of battery cells (hereafter “cells”) and the performance of pack depends on the performance of cells. The performance of cells is evaluated by the gravimetric energy density and the gravimetric power density. It is practically important that both densities are at a light level. The representative cells of various cell suppliers are selected and their gravimetric energy density and gravimetric power density are plotted on the graph in Fig. 6.

The cell performance required for an EV motocrosser can be separated to the gravimetric power density that allows the same performance as the CRF450R and to the

gravimetric energy density that permits finishing of the race. The cell is selected from the separated areas taking into account the vehicle concept and the shape of pack. In this development, the main target was set at finishing of a heat, and the cells having a higher output among those in the required area were selected.

Next, Fig. 7 shows the shapes of general cells. In the pouch type and prismatic type cells, the cuboid shape and the electrodes gathered on a side are the features. It is therefore necessary to adjust the cell shape to the cuboid shape in order to allow efficient layout. On the other hand, in the cylindrical cell, a waste space is less likely even when the external pack shape becomes complex because of the freedom of negative electrode layout and its external shape. In this development, the cylindrical cell is selected from the selection area that satisfies above-mentioned performance requirements, and worked out the L-shape pack shown in Fig. 8. This permits laying of the cells, that are the heavy objects in the pack, in the rear and lower part of the complete vehicle as Fig. 9 shows. With the L-shape pack developed, the target CG of the EV motocrosser, which is the same as the CG of CRF450R, has been attained.

3.1.2. Battery system

In the pack of general EV scooters, the range and the battery life are critical factors. Accordingly, the mainstream is such a method that maximizes the said range and life by increasing the number of parallel connections while minimizing the number of series connections of cells. With this method employed, the output voltage of battery pack

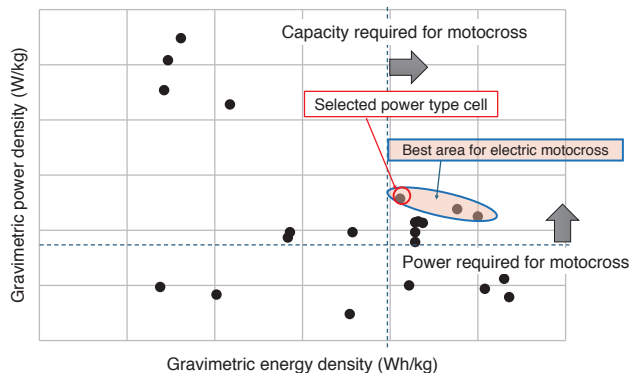


Fig. 6 Comparison of gravimetric energy density and gravimetric power density of various battery cell types

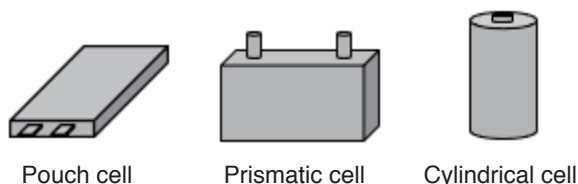


Fig. 7 General cell shapes

often falls in the zone between 50 V and 100 V.

The EV motocrosser requires battery capacity that allows finishing of the race in addition to the higher power output to stay competitive in the race. To satisfy these requirements, the cells having a higher power output explained in the preceding chapter are used, and the number of series connections are maximized to realize a higher power output as a pack. Accordingly developed is the higher voltage pack in the 400 V zone, which is the first in Honda motorcycles. Moreover, the minimum number of parallel connections is set to allow finishing of a heat race.

With the pack voltage set as high as in 400 V zone, the output current of the pack is lowered, which permits reduction of heat generation from the major components existing in the high-voltage wire lines. It also allows downsizing and weight reduction of the motor and the inverter, keeping the increase of vehicle weight of EV motocrosser less than 10% from the CRF450R.

3.2. Control System

Combining three units, i.e., the inverter integrated in the motor, the battery management unit contained in the battery pack, and the vehicle management unit that calculates driving force, the complete vehicle control system has been developed.

Introduced hereafter is the control functions employed to finish higher in the race taking advantages of characteristics of EV.

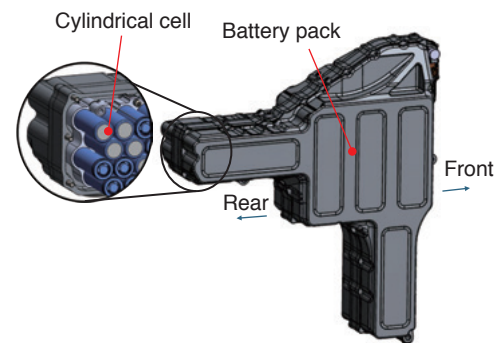


Fig. 8 Battery pack appearance and cells

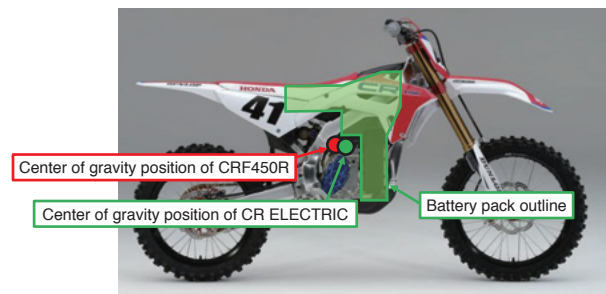


Fig. 9 Battery pack outline and vehicle CG position

3.2.1. Launch controller

To make a hole shot in motocross, it is necessary to maintain a higher driving force and power output from the start to the turn 1. However, if the driving performance specifically tuned for the start is left as it is throughout the race, the vehicle would become too difficult to control to maintain advantage in the race. We have therefore added the drive mode switching function (hereafter “launch controller”) that functions only at the time of initial acceleration when starting the race.

The launch controller is enabled from an operation when the vehicle is standing still and set by the rider before the start. Closing the throttle after starting automatically disables it. After being disabled, the ride mode will change to the mode the rider selected before enabling of the launch controller.

When starting the race, it is necessary to drive the rear wheel at the highest-possible power output while preventing wheel spin. Also, to maintain stable acceleration while preventing lifting of front wheel (wheely) when accelerating after the start, the power output characteristics were altered. Figure 10 shows power output characteristics in each mode.

At the time of start, the driving force in the low engine speeds is lowered by approximately 20% rather than merely applying the maximum power. In addition, the maximum

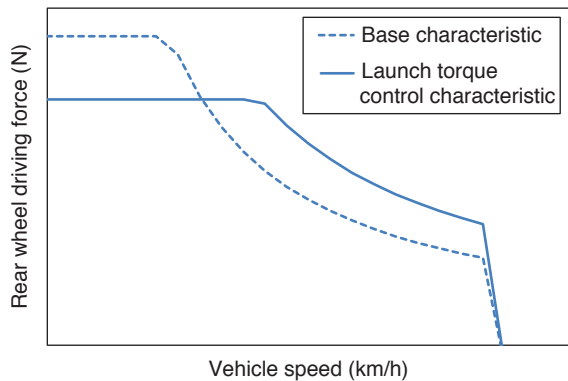


Fig. 10 Launch torque control characteristics under different operating conditions

power output is set higher by approximately 25% to reach a higher top speed. These parameters can be preset to any given value depending on the track and/or the conditions. This permits selection of optimum characteristics for each rider or race, contributing to maintaining of advantages.

3.2.2. Energy management

It is necessary to regulate electric power consumption during the race in order to efficiently consume the limited amount of installed energy. As a control application to assist that, the energy management function is added.

As Fig. 11 shows, the following are the methods to regulate electric power consumption.

- (1) To attain advantages of EV motocrosser when starting the race, a priority is given to the motor power output without considering electric power consumption when in the launch control mode.
- (2) In the race after cancelling the launch controller, the rider rides at such race-oriented output characteristics that make the output such a level that allows full use of electric power within the presumed time length of race.
- (3) The changes of electric power consumption during the race are not easy to estimate. To deal with this issue, the adequacy and the inadequacy relative to the power consumption in each lap are calculated. From the outcomes, a compensation is made by the function that adjusts output characteristics (auxiliary application).

To realize that, the output control mode is produced and the electric power consumption is measured at each designated output. Figure 12 shows plotted data indicating the relationship between the output control mode and the power consumption. Based on the data, the race mode was produced so as to set the output at such a level that allows full use of electric power within the presumed time length of race.

Also as an auxiliary application, the allowable power consumption in each lap was estimated from the remaining electric power and the remaining race length after finishing the launch control. Then, the function was added that adjusts real time the motor torque control algorithm from the linear interpolation of pre-measured output and the power consumption.

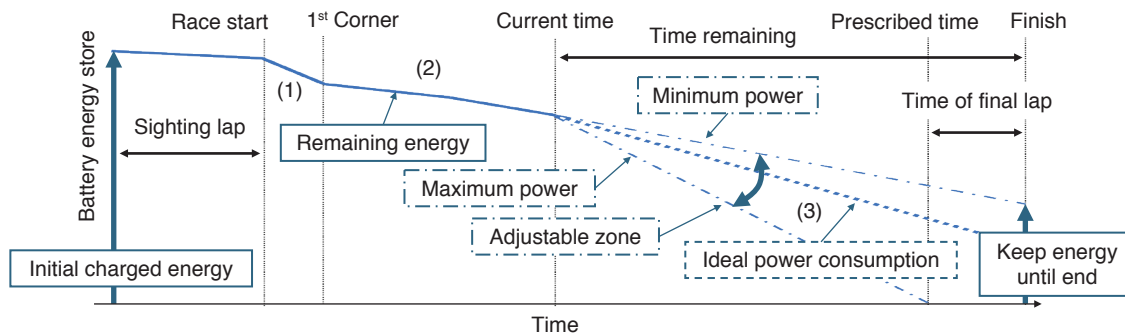


Fig. 11 Concept of battery energy management control during race

3.3. Cooling System Parts

To finish at a position higher than competition in the motocross, it is necessary to complete a heat and another race without reaching to a power restriction due to an increase of temperature. It is therefore necessary to control temperatures of various parts. In this vehicle, cooling is conducted for the motor and the inverter. As the cooling target, the following two requirements were set and the parts specifications were determined accordingly. First, the machine shall allow riding without entering the power restriction zone during a heat. Second, after cooling the parts until the next heat after completion of a heat, the machine shall allow riding throughout a race. Introduced in this chapter are the parts in the cooling system to satisfy the above requirements.

3.3.1. Setting of heat dissipation capacity

To set dissipation capacity of heat from the motor and the inverter under the race conditions of EV motocrosser, test runs were conducted using radiator cores having various surface areas. Taking temperature data of high-voltage parts from the tests, the relationship between the heat dissipation from the radiator and the part temperature during the race were measured.

Figure 13 shows the inverter temperatures when running with various types of radiators. Figure 14 shows

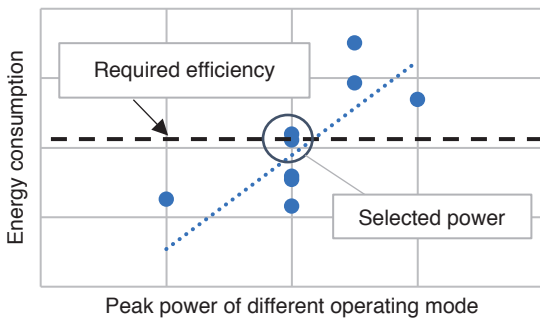


Fig. 12 Relationship between peak power of different control modes and energy consumption

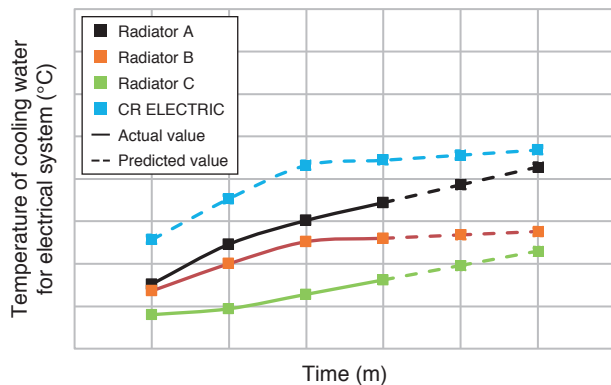


Fig. 13 Heat generation of inverter under varying operating conditions

motor temperatures when running with various types of radiators. From the test results, the power loss data of the motor and the inverter to use at this time were compared, and the amount of heat generation that determined temperatures of various parts after completing a heat was estimated. Also, from the difference of water temperature depending on the radiator core surface area, the cooling capacity per unit of radiator core surface area under motocross race conditions was estimated.

Consequently, compared to the ICEV, the radiator core surface area was reduced by 64%, and the weight was lowered by 77%. Figure 15 shows overview of the lightweight radiator. This resulted in the setting of optimum cooling performance necessary for a race as an EV motocrosser.

3.3.2. Water pump selection

In many ICE vehicles, a mechanical water pump taking power from the rotational motions of the engine is used. If a mechanical pump is used in the EV in the same manner, the pumping depends on the motor rotation. This means that the coolant circulation stops when the EV requiring no idling is staying still. Also, in the case of mechanical pump, it is necessary to lay parts on the rotational axis or drive the pump with a set of gears. Accordingly, the motor housing becomes wide sideways, causing an increase of body size.

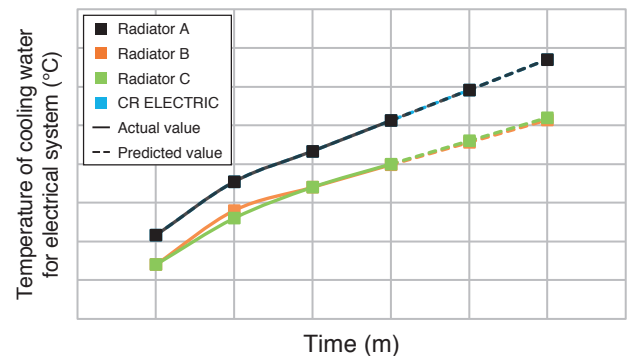


Fig. 14 Heat generation of motor under varying operating conditions

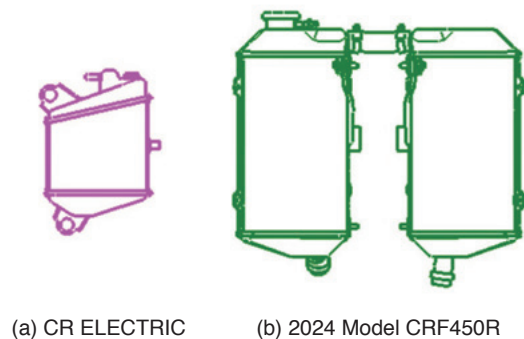


Fig. 15 Radiator size

The selection of an electric water pump to deal with the said issue allows downsizing of the power unit and permits coolant circulation when the vehicle is staying still. Thus, the specifications of cooling system to achieve the target cooling performance of EV motocrosser has been established.

3.4. Complete Vehicle

3.4.1. Specifications of complete vehicle

To allow control of vehicle as per rider's intention, we set a target at the specifications of CRF450R. Setting conditions such as the ground clearance that does not impair roadability and the fore-and-aft weight distribution that can take advantages of traction, the overall layout of electric drive train components was decided as shown by Fig.16.

Based on that, as Fig. 17 shows, the specifications of complete vehicle such as the caster angle, the trail length, the seat height, and the ground clearance were set at the same values as the CRF450R, and the wheelbase similar. Thus realized is the maneuverability necessary for the EV motocrosser.

3.4.2. Frame body

To attain required battery output and capacity, it is critical in EV motocrossers to efficiently package the battery in the limited space while minimizing vacancy. If the conventional frame body designed for the engine size of CRF450R is used, it is not easy to hold the battery having a capacity adequate for a race. Meanwhile, the stiffness of frame body affects maneuverability and stability such as nimbleness, roadability,

and turnability. Especially, as the motocross races are held on rough surfaces including jumps, the stiffness balance becomes essential. That is, a stiffness balance based on the experiences from the conventional ICEV is required.

That in mind, the aluminum, semi-double-cradle, twin-tube frame employed in the CRF450R was chosen as the basis of the main pipe. For easy installation and removal of the battery and to attain necessary frame stiffness, the cross-sectional shape of the main pipe is modified, and such a layout is employed that straightly connects the main pipes to the steering head pipe.

Figures 18 and 19 show the shapes. Said measures permit to maintain the change of frame stiffness as small as less than 10% of that of the CRF450R, assuring the same level of maneuverability as the conventional ICEV.

Also as Fig. 20 shows, to allow an adequate width for the large capacity battery, the space between the main pipes

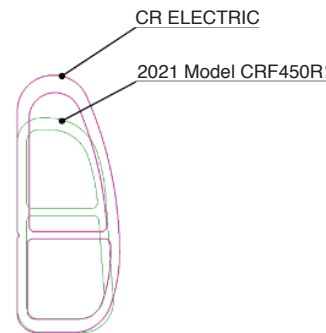
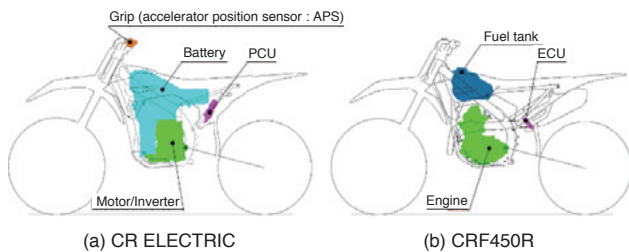


Fig. 18 Cross-sectional shape of main pipe



(a) CR ELECTRIC (b) 2021 Model CRF450R

Fig. 19 Shape of connecting part of main pipe to head pipe



(a) CR ELECTRIC

(b) CRF450R

Fig. 16 Vehicle layout

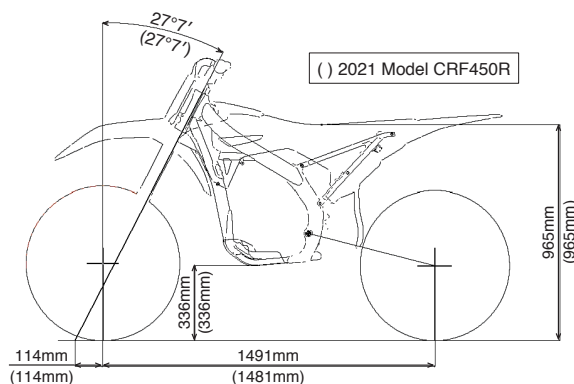


Fig. 17 Vehicle geometry of CR ELECTRIC

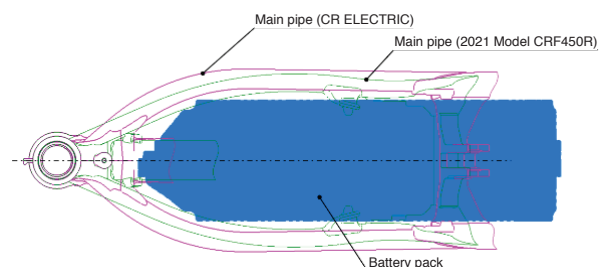


Fig. 20 Route of main pipe

is widened from right behind the steering head pipe. Also as Fig. 21 shows, the upper part of the main pipe is bent in such a manner that follows a vertical line. Accordingly, enabled is smooth installation and removal of the battery in the up and down direction of the vehicle body as Fig. 22 shows.

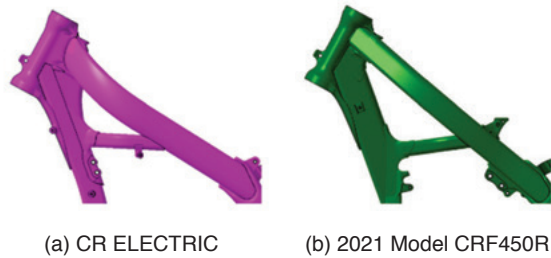


Fig. 21 Bending shape of main pipe

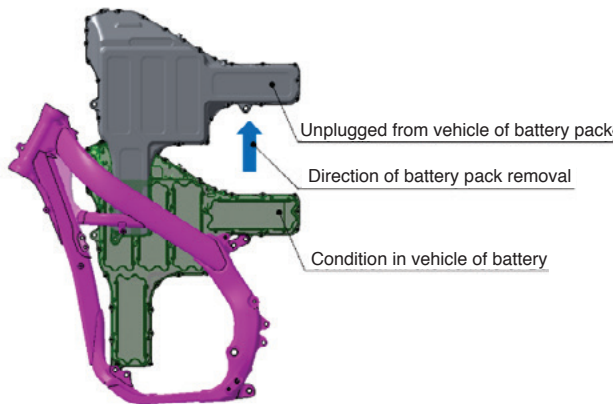


Fig. 22 Direction of battery pack removal

4. Conclusion

Through the development of EV motocrosser CR ELECTRIC, the following have been achieved.

- (1) The employment of cylindrical cells for the battery and the creation of the L-shape battery pack enabled to locate the CG of the complete motorcycle at the place similar to that of the CRF450R while attaining the target power output.
- (2) The use of battery voltage in the 400 V zone, which is the first in Honda motorcycles, reduced the heat generation from major components, allowing to achieve the light and compact package. Accordingly, enabled is the increase of vehicle weight as small as less than 10% from the CRF450R.
- (3) The newly developed ride mode switching control enables retention of power necessary for a hole shot and energy management necessary for finishing of a race as an EV motocrosser.

- (4) By estimating and optimizing heat generation in the EV components when used in motocross, we have achieved the light and compact cooling system by reducing the weight by 77% and lowering the core surface area by 64% from the CRF450R.
- (5) Despite having the component parts different from the conventional motocrosser, we have achieved the complete vehicle specifications similar to those of the CRF450R, and attained such a level of handling performance that is necessary for motocross.

To deal with a larger number of races, further increase of range and enhancement of battery charging and replacement during the race are called for. With the CR ELECTRIC brought to a reality with an aim at the motor sport in the carbon neutral era, it is now possible to hold races in urban cities and/or indoor arenas, which would enable an unprecedented appeal to users.

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