

Development of Monpal ML200 4-Wheel Scooter

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ABSTRACT

The Monpal ML200 4-wheel scooter has been developed based on the “Smart Package” concept.

Increased static and dynamic stability and greater user comfort were realized by adopting A-arm independent front and floating axle type rear suspensions and by reducing the center of gravity by locating the main parts lower down.

A metal base plate was adopted for the motor controller, while the use of a 3D map system identification speed control and a Honda-manufactured brushless motor with an integrated transmission improved efficiency and reduced drive resistance.

The scooter’s overall electrical consumption was improved by 9% over that of the current Monpal ML100 model, and a running distance of 34.3 km on a single battery charge was achieved.

Moreover, the arrangement of the lights, based on Honda ASV-3 LONG technology, has enhanced visibility.

1. Introduction

The Monpal ML100⁽¹⁾ was a pioneering 4-wheel scooter in 1999, when the market was dominated by 3-wheel models. The Monpal ML100 displayed excellent climbing performance, and was particularly well received by users in hilly and mountainous regions.

Honda’s new 4-wheel scooter, the Monpal ML200, has been developed to provide a more stable and comfortable ride, not just in hilly areas, but also in urban areas (the populations of which are expected to increase), in order to offer the joy of independent movement to even more customers.

Observation and customer surveys indicate that users of scooters in urban areas require the vehicles to be small enough not to intimidate pedestrians. They also need the vehicles to be easy to handle, so that they can, for example, be easily stored and maneuvered in and out of elevators.

Therefore, the product concept “Smart Package” was established, and the associated keywords “relaxation”, “comfort”, and “stylishness” were chosen.

2. Product Features

Figure 1 shows an external view and Fig. 2 shows a design sketch of the Monpal ML200; the scooter’s major specifications are shown in Table 1.

• Design

The design concept for the Monpal ML200 was “Quality Life – A relaxing, comfortable and stylish vehicle that increases the richness of daily life.” The design used has a low center of gravity and offers a sense of stability even with a slim and compact body.

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Table 1 Major specifications

Items	Specifications	
Model name	New Monpal ML200 (DX)	Monpal ML100 (DX)
Overall length (mm)	1,190	1,190
Overall width (mm)	595	680
Overall height (mm)	1,045	1,080
Tread (mm)	500	Front: 590/Rear: 530
Vehicle weight (kg)	112	94
Tire size	80/80-6	Front: 3.00-4 Rear: 70/100-8
Batteries	Valve Regulated Lead Acid 12V-35AH $\times$ 2	
Motor (30 min. rated output)	DC brushless motor (24V 430W) $\times$ 1	DC brush motor (24V 360W) $\times$ 1
Drive system	Direct 2-rear-wheel drive system (with differential)	
Brakes	Electromagnetic brake, regenerative brake, manual brake	
Max. speed (km/h)	6	6
Min. turning radius (mm)	1,430	1,470
Max. continuous driving range (Until stopping) (km)	34.3 (6km/h on level surface)	31.6 (6km/h on level surface)
Max. driver weight (kg)	100 (including baggage)	100 (including baggage)



Fig. 1 External view of Monpal ML200



Fig. 2 Design sketch

- (1) A front face with a welcoming look
 - (2) A front fender offering maneuverability
 - (3) A front panel with a U-shaped pillar design offering robustness, i.e. protection to the user, and a rear panel extending from the floor
- Convenient package
The width of the Monpal ML200 has been reduced by 85 mm to 595 mm, equivalent to the width of a bicycle. This new profile is highly convenient when driving the scooter, storing it when not in use, or maneuvering it in and out of an elevator. A front fender has also been added to make it easy for users to see which direction the wheels are pointing, resulting in excellent handling.
 - Comfortable ride
The use of front and rear suspensions has enabled the achievement of a balance between user comfort and stable handling.
 - Confidence-inspiring running performance
The use of a Honda brushless motor with integrated transmission and a motor controller featuring 3D map system identification speed control has enabled the achievement of a traveling distance of 34.3 km on a single battery charge and minimal reduction in vehicle speed when climbing hills.
 - Advanced drive system
Right and left driving levers, forward/reverse switching with automatic reset connected to the power source, large, clearly visible indicators, and a blinker switch with a canceller provide ease of use and a sense of security.
 - High visibility
Honda ASV-3 LONG technology is used on the body's side surface, and lights are arranged lower on the body, enhancing the user's sense of distance. The lights have also been increased in number and placed in a higher position, increasing visibility to vehicular traffic.
- This paper will discuss the body, power train and control technologies that have been used to develop the main features of the Monpal ML200: A smart package, user comfort and security, and driving performance offering peace of mind.

3. Body Technologies

3.1. Ensured Stability

The following points describe the differences between a scooter and a normal vehicle.

- The driver's weight is high relative to vehicle weight (approximately 100 kg), but ensured stability through shift of the driver's weight cannot be expected.
- There is a wide projected range of driver weight (40-100 kg).
- Vehicle dimensions are specified by the model standard, as follows: (Total length × total width × total height): 1200 mm × 700 mm × 1090 mm or shorter.
- Load shifting on inclines is high due to the comparatively high center of gravity.
- Considerations of ease of entry and exit, field of vision, and comfort place limits on the degree to which the sitting position can be lowered.
- Ease of use requires a turning radius of less than 1.5 m, and to achieve this, a turning angle of more than 55 deg. is required for the inner wheel.
- Drive and braking are dependent on the rear wheels, and it was therefore necessary to use a 30/70% front to rear weight ratio to ensure stable traction and braking force.

Given these restrictions, the development issues were to ensure stability while reducing the width of the Monpal ML200 against the Monpal ML100 and using a suspension system to increase user comfort.

3.1.1. Static stability

The reduction in static stability caused by the reduction in the width of the wheels was addressed by lowering the center of gravity of the vehicle.

Specifically, a low position layout of heavy accessories such as batteries, an increase in weight from using urethane-filled puncture-less tires, and addition of a suspension system and a swiveling seat mechanism lowered the vehicle's center of gravity by 22 mm against the Monpal ML100, resulting in an increase of approximately 5% in static turnover angle on inclines.

3.1.2. Dynamic stability

An important dynamic stability issue for the scooter was to help prevent lateral rollover when the user operates the steering handle while the vehicle is descending an incline.

The following three scenarios can be suggested as causing instability on an incline (Fig. 3):

- (1) The angle of the incline exceeds the scooter's lateral stability
- (2) The sum of the angle of the incline and the lateral G force (incline direction component) during a steady turn exceeds the scooter's lateral stability limit
- (3) The roll induced by the lateral G force during a turn causes the back inner wheel to leave the ground; the differential operation makes the sum of the lateral G force (incline direction component), increased by the acceleration due to the incline, and the angle of the incline exceed the scooter's lateral stability limit

It is difficult to imagine scenarios (1) and (2) occurring on a normal paved incline. However, scenario (3) is dependent on the characteristics of the vehicle, and in some cases scooters can become unstable under limited conditions in this scenario.

The following methods were used to control the scenarios described above:

- (1) Ground contact during a turn has been enhanced by imparting a degree of freedom to the rear suspension in the direction of roll (discussed below).

- (2) The timing of deceleration against the steering wheel angle was changed, and the ability of the deceleration control to follow rapid turning of the steering handle was increased.

As a result of these modifications and of lowering the scooter's center of gravity, as mentioned previously, the vehicle's dynamic stability has been enhanced despite the reduction in the width of the wheels.

3.2. Increased Comfort

There are numerous indented and raised sections such as stepped areas in sidewalks and curbs, joints and repairs in paving, manhole covers, pedestrian crosswalk paint, and steel plate surfaces used to prevent slipping. These cause impacts and vibrations to be transmitted to the seat and the steering handle. The Monpal ML200 has been fitted with front and rear suspensions to absorb these impacts and vibrations and increase user comfort.

3.2.1. Front suspension

The configuration of the front suspension is simple, with an A-arm and shock absorber used on each side. The left and right sides are independent. This configuration has significantly increased the camber, but changes in grip and potential uneven wear were judged, based on operating conditions (vehicle speed, lateral acceleration, etc.), to be within acceptable limits.

A multi-stage wheel rate was used to maximize sinking when the driver sits on the seat. This produces a more comfortable ride and enhances stability by ensuring ground contact when the load is reduced on steep hills despite the fact that a low load is distributed to the front of the vehicle.

The configuration helps control instability, such as when the vehicle is on an incline or affected by the push-under that occurs when the steering angle is altered to start the vehicle on a low μ surface, resulting in a level of handling that enables even the elderly to operate the vehicle with confidence.

In addition, the caster angle and kingpin angle were set to 2° and 7° respectively to reduce steering force (Monpal ML100 - caster angle: 5°, kingpin angle 10°). This minimizes the restorative force to allow for extended use by elderly users with limited muscular power.

Because the scooter basically stops when the user takes his or her hands off the handle, excessively strong neutral restorative force is not necessary. Therefore, the setting prioritizes comfort of the steering handle operation.

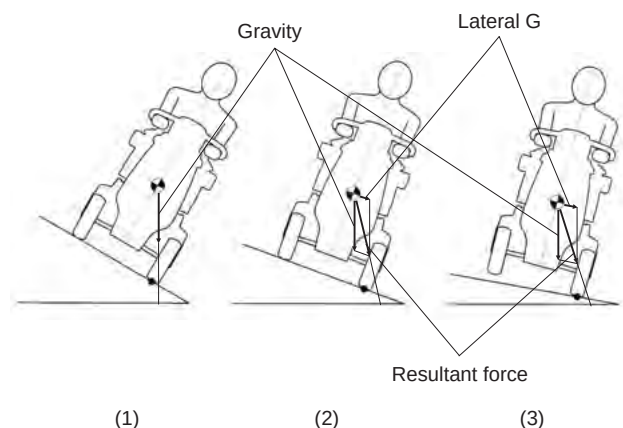


Fig. 3 Unstable vehicle model

Figure 4 shows the configuration of the front suspension, and Fig. 5 shows the relationship between front tire load and movement.

3.2.2. Rear suspension

The rear suspension generally used in scooters possesses a one degree of freedom link; this allows only an up-down motion supported by the left and right trailing arms of the motor/transaxle unit.

The rear suspension used in the Monpal ML200 is a floating axle type that possesses a two degrees of freedom link, allowing motion in the direction of roll using a pivot at one point on the frame of the trailing arm and rubber bushings at two points on the transaxle coupling. Studies of stability, comfort, and strength indicate that a lateral rod is not required.

Roll stiffness was controlled by adjusting the hardness of the three bushings used on each side of the vehicle and the lateral mounting span of the shock absorber. The bushing on the frame

has been recessed to ensure that it flexes easily in the direction of roll, which increases road holding when one wheel comes off the pavement and runs on a raised section, or when roll occurs. It also increases comfort.

Figure 6 shows the configuration of the rear suspension, and Fig. 7 shows the frame bushing cross section.

3.2.3. Tires

Urethane foam-filled puncture-less tires have been specially designed in place of the previous pneumatic tires to prevent anxiety over getting a puncture while out on a journey. Factors such as the shape of the tread and the hardness of the urethane (necessary for balancing comfort and running resistance), and the patterns required to achieve stable traction and braking force with changes in the pavement surface were decided on the basis of a variety of tests.

Figure 8 shows the tire structure and pattern, and Fig. 9 shows the contribution made to riding comfort by tire and suspension.

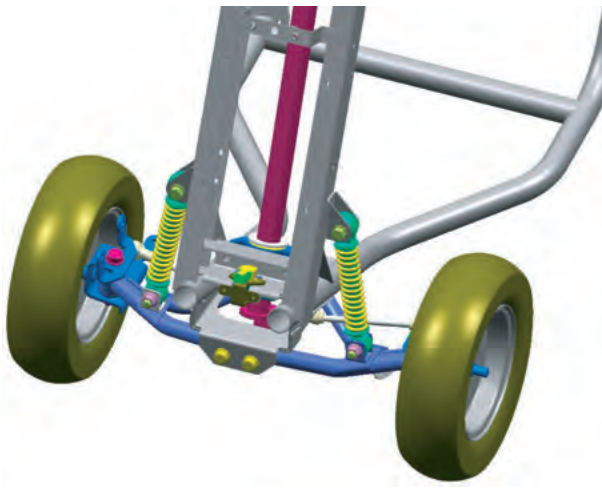


Fig. 4 Front suspension

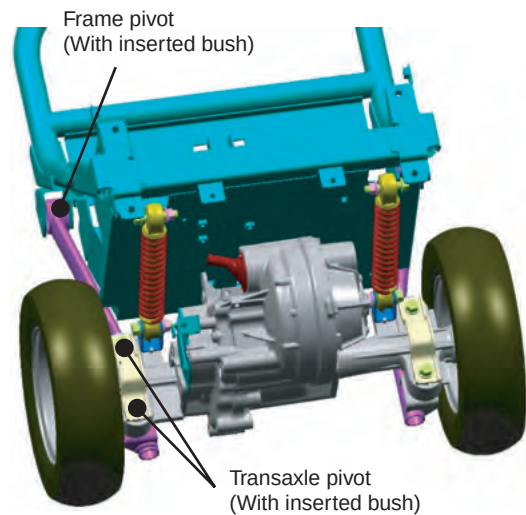


Fig. 6 Rear suspension

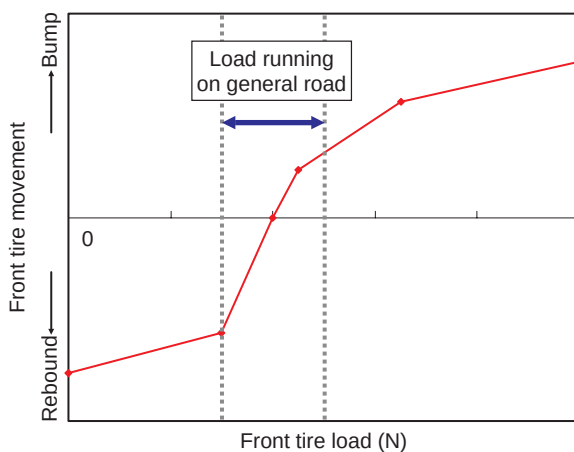


Fig. 5 Relationship between load and movement

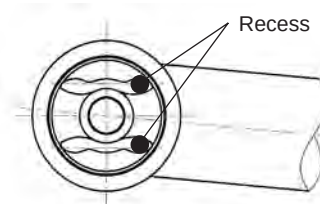


Fig. 7 Frame bush cross section

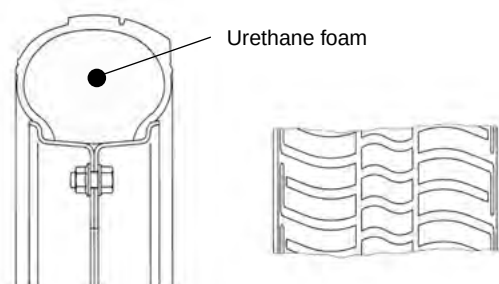


Fig. 8 Tire structure and pattern

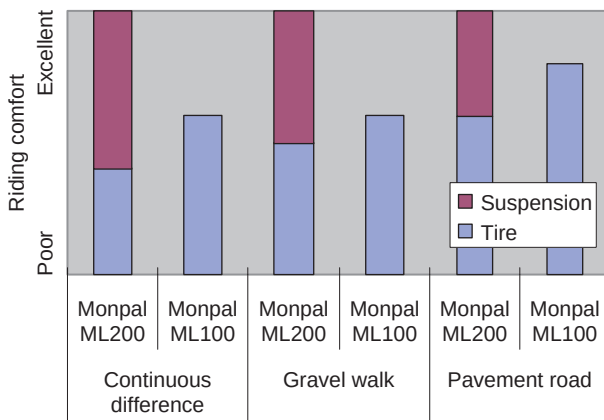


Fig. 9 Contribution to riding comfort

4. Power Train Technology

4.1. Power Train Configuration

In the power train, an original brushless motor is used for drive, and integrated with the gear case. This configuration reduces the number of parts and prevents gear noise from being generated by motor/gear case mounting tolerance.

Electromagnetic brakes are mounted on the motor shaft. The system detects the ON/OFF state of the power switch and driving lever and the speed of the shaft, and controls operation of the electromagnetic brakes, enabling the brakes to be applied while the vehicle is stationary. This allows the brakes to operate automatically, even when the scooter is stationary on an incline, ensuring that it remains immobile.

The gear case has three shafts; the clutch and the manual brake are mounted on the second counter-shaft.

A shifter enables the spline that runs between the counter-shaft and counter-driven gear to be disconnected to allow the shaft to move freely when the scooter is pushed manually, when the battery loses charge or during a malfunction.

The manual brake is operated by a brake lever provided with a lock mechanism. The brake is a standard internal expansion drum brake, and is used when the scooter is being pushed manually or when it is parked.

Figure 10 shows the structure of the power train.

4.2.2. Semi-closed slot stator

As methods to achieve smooth output RPM in a drive motor, a skewed pole configuration or a closed-slot stator are commonly used. However, both reduce magnetic flux, leading to a reduced power density for the same size of motor.

The new motor uses a stator with a semi-closed slot configuration. In addition, by optimizing the width of the magnet and the depth to which it is inserted in the IPM rotor, smooth revolution and high output are both achieved.

Figure 11 shows the configuration of the semi-closed slot stator.

4.2.3. Thicker wiring and internal bus ring configuration enabled by use of split-core stator

The use of a split-core stator enables bobbin winding of the coils. In addition, the use of self-fusing wires for windings enables the usual varnishing process to be eliminated.

When using a split-core stator, it is necessary to connect the concentrated windings of the coils at the core. In the new motor, the ends of the coils are positioned at the inner circumference of the stator. For this reason, the connections between the coils and the bus ring protrude into the inner circumference of the stator. This enables the electrode structures to be simplified and reduced in size, resulting in a reduction in the length of the wires and reduced electrical resistance.

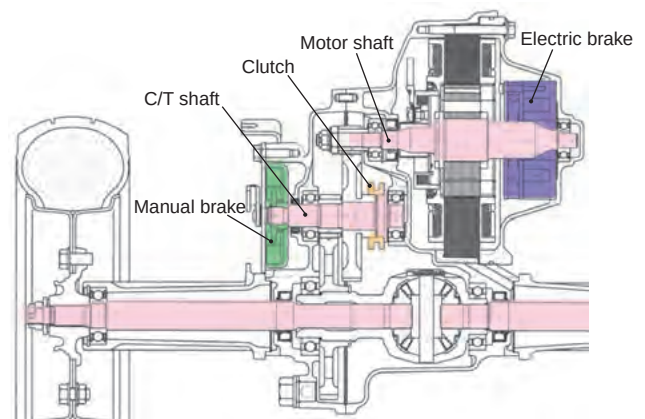


Fig. 10 Structure of power train

4.2. Integrated Motor/Transmission

4.2.1. IPM rotor

The Monpal ML100 used a Surface Permanent Magnet (SPM) rotor with a magnet attached to the core. Armature reaction in these rotors caused demagnetization at high temperatures and high loads.

The new scooter uses an Interior Permanent Magnet (IPM) type rotor that uses a flat plate magnet. This allows reluctance torque to be used at low speeds and field weakening control to be applied at high speeds. As a result, the weight of the magnet has been reduced, while the range of operation has been increased.

This IPM rotor was first used by Honda in the hybrid snow thrower HSS1170i, and is manufactured by the company's Kumamoto Plant⁽²⁾.

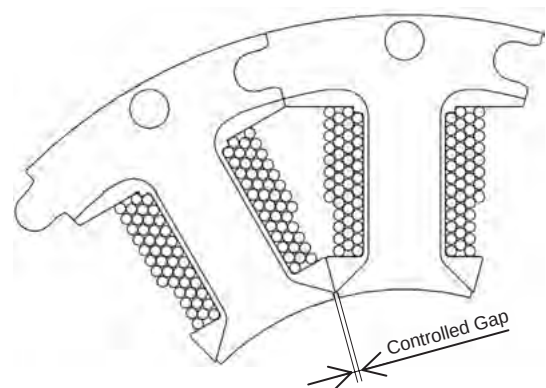


Fig. 11 Semi closed stator

4.3. Increased Drive System Efficiency

The traveling distance of a scooter on a single battery charge is an important performance indicator. The efficiency of the drive system used in the Monpal ML200 has been enhanced to achieve the development target of an increase of at least 5% in traveling distance against the Monpal ML100 (running on the flat road at 6 km/h).

In addition to using a high-efficiency drive system (to be discussed below), other measures used to increase efficiency include the optimization of motor speed and the use of low-friction sealed bearings in the motor to reduce electricity consumption, resulting in the achievement of a 0.2 A reduction in consumption against the Monpal ML100.

0W-20 oil, which is now being used in fuel-efficient engines, was adopted as the transmission oil, and agitation resistance equivalent to 0.1 A of current consumption was reduced.

Application of voltage duty control (75%, 500 Hz) to the electromagnetic brakes after they are released has reduced the effective voltage, resulting in a 0.1 A reduction in expended current.

As a result of these measures, the electrical consumption of the vehicle has been improved by 9% over that of the current Monpal ML100 model, and the running distance on a single battery charge of 34.3 km (DX type actual value) was achieved.

Figure 12 shows a comparison of current consumption in the Monpal ML100 and the Monpal ML200.

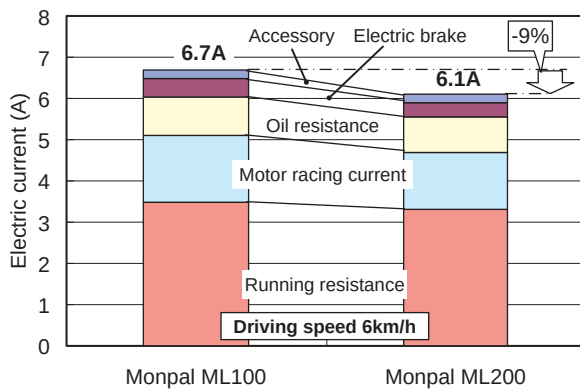


Fig. 12 Comparison of current

5. Control Technologies

5.1. High-efficiency Drive System

The use of a metal base plate for better heat radiation and 3D map system identification speed control technology for an enhanced power characteristic has resulted in the achievement of increased efficiency in the motor controller and has also enabled the unit to be reduced in size.

Figure 13 shows a comparison between the new brushless motor used in the Monpal ML200 and the brush motor used in the Monpal ML100.

5.1.1. Motor controller with metal base board

Reducing the size and weight of the motor controller while increasing power necessitated increased heat radiation performance for the drive section which produces the most heat in the unit. A

5 mm thick aluminum base board was therefore used in the motor controller.

In addition, the motor controller was coupled by bolts to a 1.2 mm thick steel frame located underneath the seat, with a heat radiation sheet sandwiched between.

Figure 14 shows the layout of the motor controller in the vehicle.

This configuration has enabled the heat generated by the motor drive section to be dispersed by the aluminum plate and radiated directly from the steel frame, enabling the previously used heat sink to be eliminated.

As a result, it was possible to increase the power of the motor controller while reducing its size and weight, and the efficiency of the unit was increased by 5% against the Monpal ML100.

Figure 15 shows a comparison of the motor drive systems used in the Monpal ML100 and the Monpal ML200 at a vehicle speed of 6 km/h.

5.1.2. Three-dimensional map system identification speed control

The optimization of power distribution patterns in response to motor speed and torque was essential to maximizing the potential of the IPM rotor/DC brushless motor.

The new system estimates output torque based on the difference between the RPM that are demanded by external input and actual RPM. It then calculates the duty values, lead angle and turn-on angle required to achieve the estimated torque using a 3D ROM map. These calculations are conducted in real time to enable stable speed control to be applied.

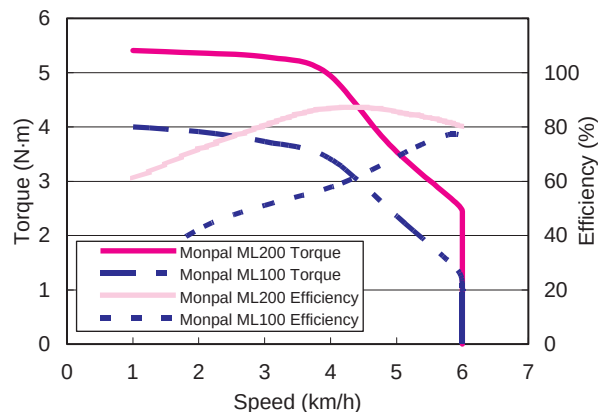


Fig. 13 Comparison of power & efficiency

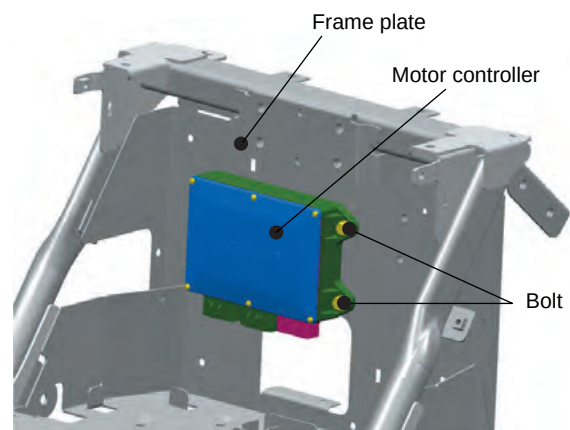


Fig. 14 Layout of motor controller

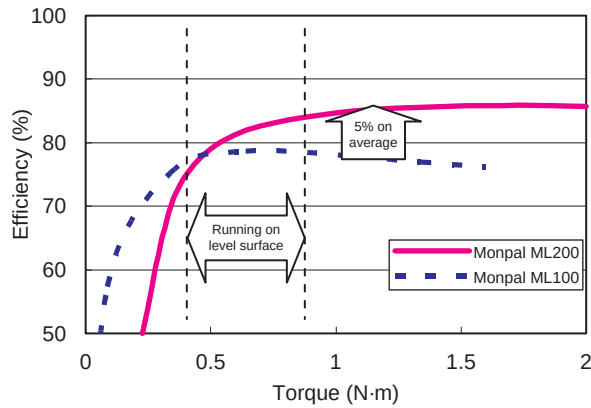


Fig. 15 Comparison of motor efficiency

Because the motor in the new system uses an IPM rotor and concentrated windings in the stator, an electromagnetic field model of optimal speed control would be extremely complex. For this reason, the 3D ROM map of duty value, lead angle and turn-on angle mentioned above are determined on the basis of calculations that are conducted in advance as well as from actual measurements.

Figure 16 shows representative characteristics of a 3D map of DUTY.

5.2. Other Control Technologies

5.2.1. Turning deceleration control

Generally, the scooter is provided with turning deceleration control that limits the maximum speed of the vehicle in response to the driver's steering handle input. This enhances drive feel and vehicle body stability during turns.

In the Monpal ML100, the handle input was detected according to ON/OFF states of a turning switch positioned radially on the steering shaft. To enhance detection of the degree of input to the steering shaft, steering input is detected in the Monpal ML200 using a potentiometer driven by the steering shaft via gears. Because

there is a linear relationship between the handle input from the driver and the potentiometer output value, a linear deceleration control according to the value enables smoother turning deceleration.

Figure 17 shows the relationship between setup speed and steering rate inside the motor controller. If the vehicle speed is higher than 4 km/h, it will be reduced to 4 km/h when the handles are operated. Equation (1) shows the relationship between these parameters.

$$Ncd = Ncm \times Rst$$

$$Nset = Niset - Ncd \quad (1)$$

Ncd: Degree of reduction of maximum speed

Ncm: Vehicle speed prior to turning deceleration

Rst: Turning ratio based on steering potentiometer reading

Niset: Setup speed based on operation of the accelerator by the user

Nset: Actual setup speed

5.2.2. CAN communication

The Monpal ML200 uses two ECUs with different functions, in the control panel and the motor drive section. Controller Area Network (CAN) communication is used to transmit information between these control units.

The vehicle uses a drive-by-wire (DBW) system in which the control panel ECU receives signals from the driving lever, the front-rear switch, the volume for maximum speed settings, and the steering sensor, and transmits this information via CAN communication to the motor drive ECU, which uses them to apply optimum motor drive control.

The use of CAN communication provides the following benefits:

- (1) The drive section, which radiates a significant amount of heat, can be concentrated in one section.
- (2) The harnesses used for operating controls can be significantly shortened.
- (3) The harnesses used for running control can be reduced by about 50% in number compared to the current Monpal ML100.
- (4) Advanced malfunction diagnostics can be applied because the ECUs are separated by function.

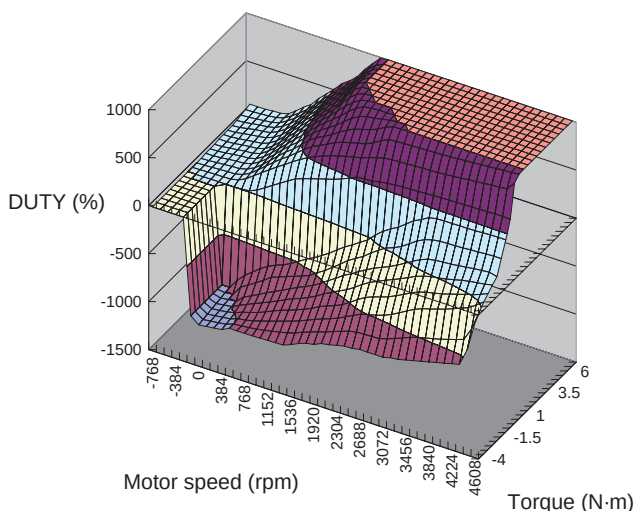


Fig. 16 Three-dimensional map of DUTY

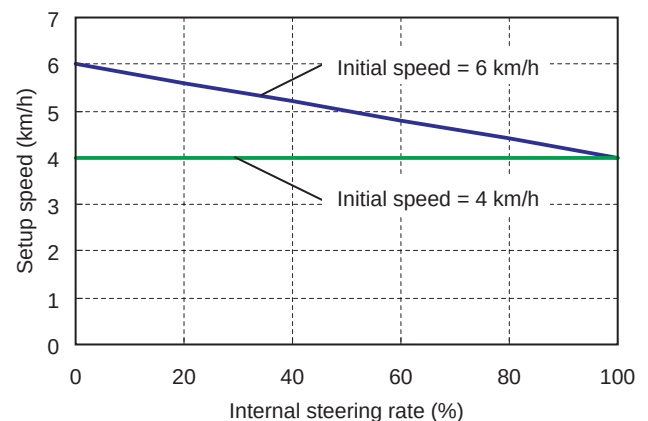


Fig. 17 Relationship between setup speed and internal steering rate

6. Conclusion

Using new suspension configurations and lowering the vehicle's center of gravity have increased steering stability and user comfort. The achievement of increased efficiency through the use of 3D map system identification speed control and a Honda brushless motor with an integrated transmission has increased the traveling distance on a single battery charge.

These body, power train, and control technologies have allowed realization of the "smart package" development concept, with the keywords "relaxation," "comfort" and "stylishness."

As a result, the Monpal ML200 4-wheel scooter is easier to use than the current Monpal ML100, and will undoubtedly be used with satisfaction by numerous customers.

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