

Development of Honda E-Clutch System for Motorcycles

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ABSTRACT

We have developed the Honda E-Clutch system, which allows starting, gear shifting, and stopping without manually engaging or disengaging the clutch while permitting manual clutch operations when necessary. The clutch actuator added to the existing engine enables controlling the clutch automatically. With the three-split construction employed in the engine-side clutch lever and by the appropriate detection of rider's manual clutch operation, the system permits smooth change over from automatic to manual and vice versa. Equipped with the automatic clutch, the rider can now enjoy sportier and easier riding than before while maintaining an option of manual clutch operations. The system is configured to minimize restrictive factors in mounting the new system to the vehicle so that it is applicable to various types of motorcycles.

1. Introduction

Recently in the FUN category motorcycles (predominantly for the hobby), such drivetrain systems requiring no clutch operations like the dual clutch transmission (DCT) and the quick shifter have been developed and applied to mass-production motorcycles. The DCT is an automatic transmission (hereafter as AT) system composed of two hydraulically-controlled clutches and a specifically-designed transmission gear box, allowing starting, gear shifting, and stopping without manually operating the clutch. Upshifting and downshifting of the gear are also automated. The quick shifter uses the conventional manual transmission (hereafter as MT) gear box, and although manual clutch operations are necessary when starting and stopping, the gear can be shifted just by the pedal operation because the engine is controlled cooperatively for upshift or downshift of the gear. Since rider's controls from the clutch lever are reduced by such a system, the rider can travel at ease and concentrate on riding, which allows even sportier riding. Such a system, therefore, is well accepted by motorcycle users, and its applications have been increasing in recent years. In the meantime, it is necessary to accurately estimate clutch capacity in order to precisely control the clutch automatically by the electronic control system as seen in the DCT. Accordingly, such a system configuration using a hydraulic system is commonly employed. In the system consisting of a hydraulic control system, however, there

were issues with an increase of the number of component parts and the difficulty of packaging in the limited space. Unlike automobiles, the motorcycle has a high degree of freedom in the maneuver of vehicle such as banking and wheeling, demands are still high for control of vehicle by an instant adjustment of traction by manually operating the clutch. A system like the DCT having no clutch lever cannot deal with such a demand. Accordingly, required is such a system that allows both automatic and manual control of the clutch and fits easily in the limited space.

To deal with such demands, using the compact and easy-to-mount clutch actuator, the Honda E-clutch system has realized starting, gear shifting, and stopping without manually operating the clutch while maintaining the same configuration of existing MT and allowing conventional manual clutch operations. This paper introduces the objectives of the system, the configuration and overview of operations, the automatic control of clutch to realize target functions, and the switching from the manual clutch operation to the automatic clutch control and vice versa.

2. Development Goal

The authors consider that there is a joy of riding and controlling the "FUN" motorcycle using right and left hands, right and left feet and body actions, having the rider's body is augmented, the motorcycle becomes a part of rider's body, rather than a mere means of transportation. Among such actions, even the efforts of clutch operation

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and/or gear shift are a pleasure and add such a value that is an essence of fun. (An appeal of MT) On the other hand, there are some operations that some riders don't prefer to perform depending on the situation. Examples are listed below.

- Clutch operation when the engine can stall at the time of starting or stopping, or when the rider is afraid of a tip over when standing still.
- Clutch operations in traffic congestion or when the rider is tired after a long-distance travel.
- Clutch operation when pronounced instability may occur in the motorcycle when down-shifting the gear.
- Shifting the gear to neutral when stopping at a traffic light

Such “undesirable operations” can be eliminated by automating clutch operations.

The automated clutch operations can also stabilize motorcycle behavior when sports riding in twisty roads by delicately controlling the clutch just like the expert riders do. This allows the rider to concentrate on the throttle control, braking, gear shifting, and motorcycle maneuvering

for “sportier” riding. Thus, the addition of automatic clutch control while maintaining the manual clutch operation makes the FUN motorcycle more user friendly and adds even more “fun.”

The Honda E-Clutch system has satisfied the above-mentioned requirements by the simple system configuration applicable to existing engines. This system is aimed at providing a wide variety of riders from the beginners to experienced ones with the opportunity of next level riding (sportier, easier, and more flexibly). Anything the rider can do in the MT can also be performed in the new system which is upward compatible with the MT. Figure 1 compares various functions of MT, quick shifter, Honda E-Clutch, and DCT.

The Honda E-Clutch system requires no manual clutch operation when starting or stopping. Shifting up or down can be performed just by the shift pedal operation. The rider can also engage or disengage the clutch manually from the clutch lever on the handlebar.

Clutch type Operation	Single clutch			Dual clutch
	Conventional manual transmission	Quick shifter	E-Clutch	DCT
Start	Clutch lever and throttle operations 	Clutch lever and throttle operations 	Throttle operation only 	Throttle operation only 
Gear change	Clutch lever and shift pedal operations 	Shift pedal operation only 	Shift pedal operation only (Automatic clutch control) 	No operation needed (Automatic gear change / Voluntary operation possible) 
Stop	Clutch lever and braking operations 	Clutch lever and braking operations 	Braking only 	Braking only 
Manual clutch control	Possible	Possible	Possible	No setting

Fig. 1 Drivetrain system types and operations

3. System Configuration and Functioning

3.1. System Configuration

In the FUN motorcycle, it is necessary to configure the system while minimizing weight increase and its influence on the component layout. That in mind, we added the clutch actuator and the motor control unit (hereafter as MCU) for automatic controls of the clutch actuator to the basic

motorcycle having a MT as shown in Fig. 2. The shift sensor similar to the one in the quick shifter is incorporated into the gear shift pedal to detect rider's shifting effort.

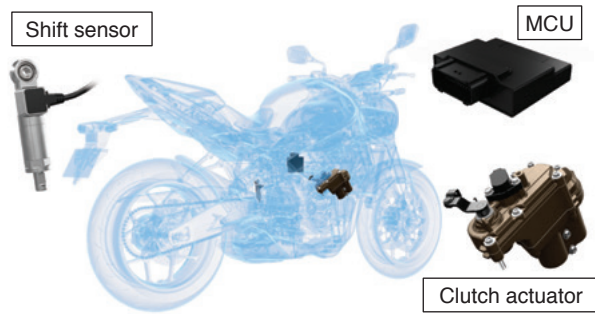


Fig. 2 Components layout

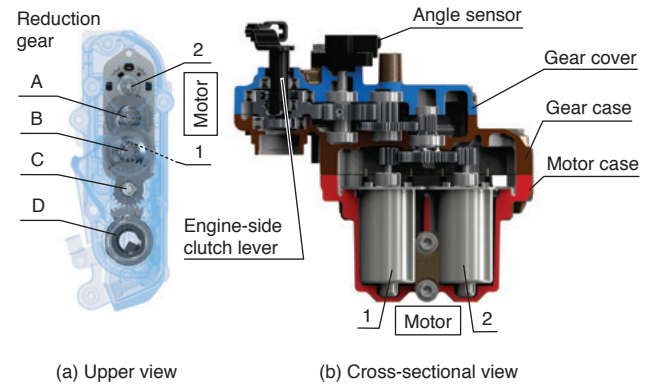
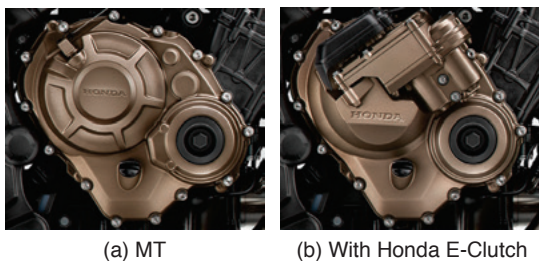


Fig. 4 Internal structure of clutch actuator

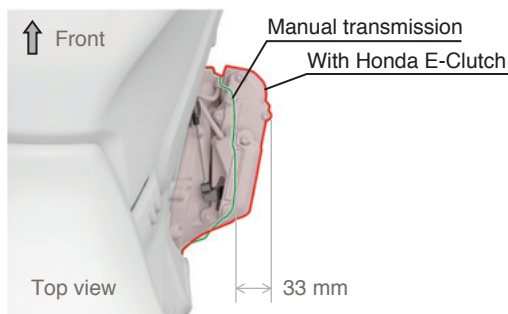
Figure 3 compares views of right-side covers of the MT model and with Honda E-Clutch model. As apparent from the picture, the clutch actuator is attached to the engine cover on the right-hand side of the vehicle. The system is configured in such a manner that the motor directly controls the clutch. With this configuration employed, the engine cover is the only part that requires extensive modifications.

Regarding the mounting of clutch actuator, the three-tier construction is employed for the clutch actuator case to accommodate a higher reduction ratio as shown in Fig. 4. Rather than using a single large motor, two small motors are used to narrow down the clutch actuator while maintaining the necessary motor power, which contributes to the increase of width as small as 33 mm to the right-hand side of the engine as shown in Fig. 3 (c)⁽¹⁾.



(a) MT

(b) With Honda E-Clutch



(c) Comparative image of engine side cover protruding to the right

Fig. 3 Appearance and size comparison between MT and with Honda E-Clutch

This system requires a changeover of clutch control state from automatic clutch control to manual clutch operation and vice versa.

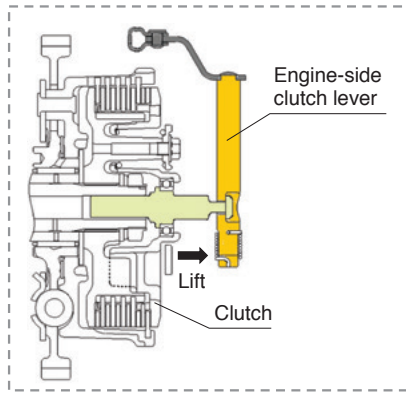
Figure 5 (a) shows the cross-sectional view of a conventional manual clutch. As the rider grabs the clutch lever, the force is transmitted via the clutch cable to the engine-side clutch lever, which turns and lifts the clutch to cut off driving force transmission.

In the Honda E-Clutch, the three-split construction is employed in the engine-side clutch lever of the clutch actuator as shown in Fig. 5 (b), which permits overriding in the direction of disengagement to satisfy the earlier-mentioned requirements⁽²⁾.

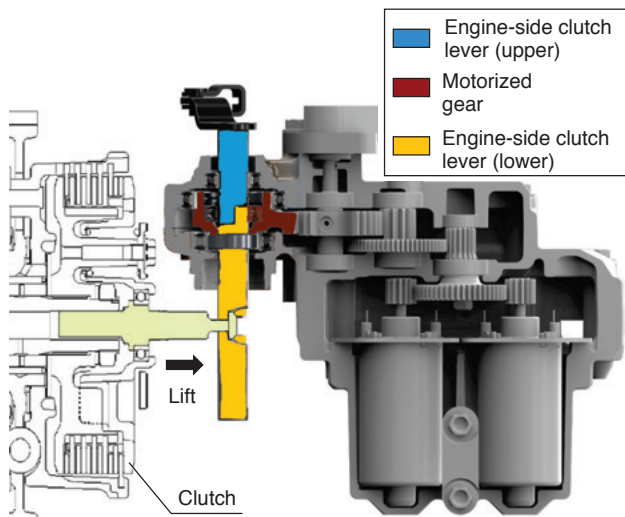
As shown in Fig. 5 (b), the left hand clutch lever is linked via the cable to the engine-side clutch lever (upper side) colored blue.

As the rider grabs the clutch lever, the clutch lever on the engine side turns, which turns engine-side clutch lever (lower side) colored yellow to operate the clutch as shown in Fig. 6 (a).

As shown in Fig. 6 (b), when automatic, the motors turn the gears colored brown, which turns the engine-side clutch lever (lower side) colored yellow to control the clutch. When the rider grabs the clutch lever while the clutch is controlled automatically, the engine-side clutch lever (upper side) drives the engine-side clutch lever (lower side) in the form of overtaking the gear, allowing overriding by the manual clutch operation, as shown in Fig. 6 (c). With this configuration employed, the motorcycle can be ridden as a standard MT vehicle in case the automatic system fails.



(a) Conventional engine-side clutch lever mechanism



(b) Honda E-Clutch lifter

Fig. 5 Engine-side three-split clutch lever mechanism

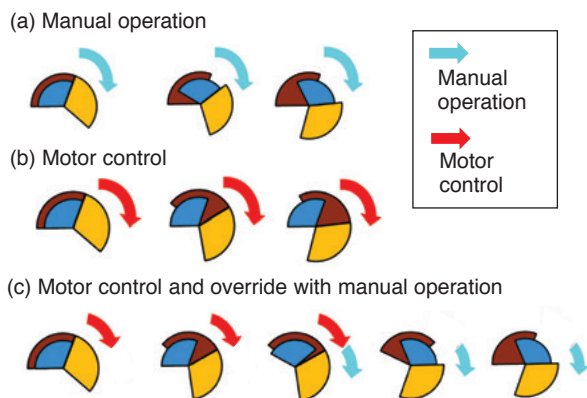


Fig. 6 Cross-sectional view of clutch lever operation diagram for engine-side three-split clutch lever

As shown in Fig. 7, the clutch actuator is controlled by the dedicated controller called MCU. The MCU receives vehicle information from the FI ECU via CAN and

appropriately controls the clutch depending on the vehicle status and the clutch actuator conditions (angle sensor output and motor current).

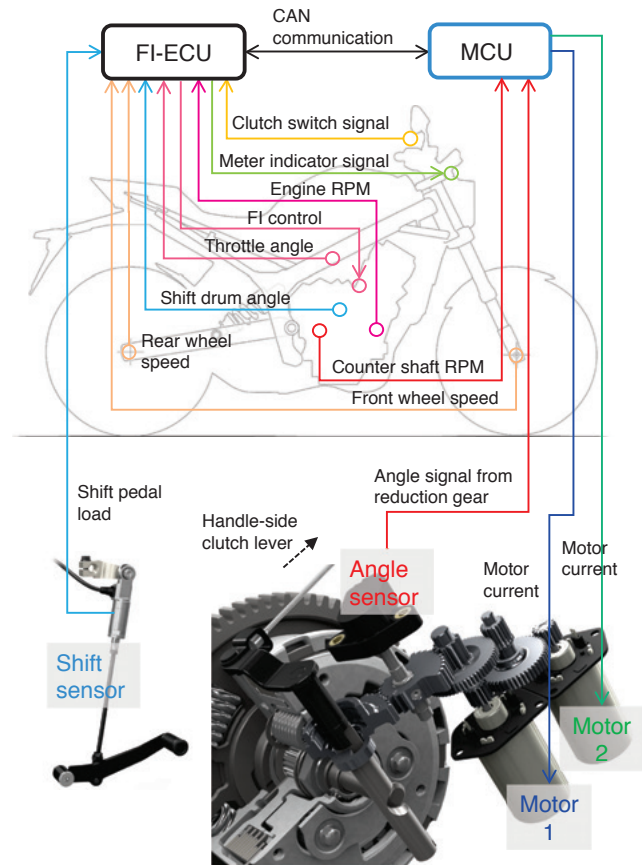


Fig. 7 System configuration overview

The above-mentioned system configuration excels in mount-ability and allows addition to existing engines.

The Honda E-Clutch system weighs only 2 kg, which is 1/5 of the DCT which is 10 kg.

3.2. Overview of System Operations

Figure 8 shows overview of operations when the Honda E-Clutch system is enabled (system is ON). When the ignition key is turned ON with the gear position at neutral and the engine is started, the system turns to the automatic control state as indicated in the green frame as shown in Fig. 8. Under these conditions, the rider can start, shift gears, and stop without using the clutch lever. Whether the automatic clutch control is enabled or disabled can be checked by the lighting of the indicator in the meter as shown in the lower right of Fig. 8.

System ON

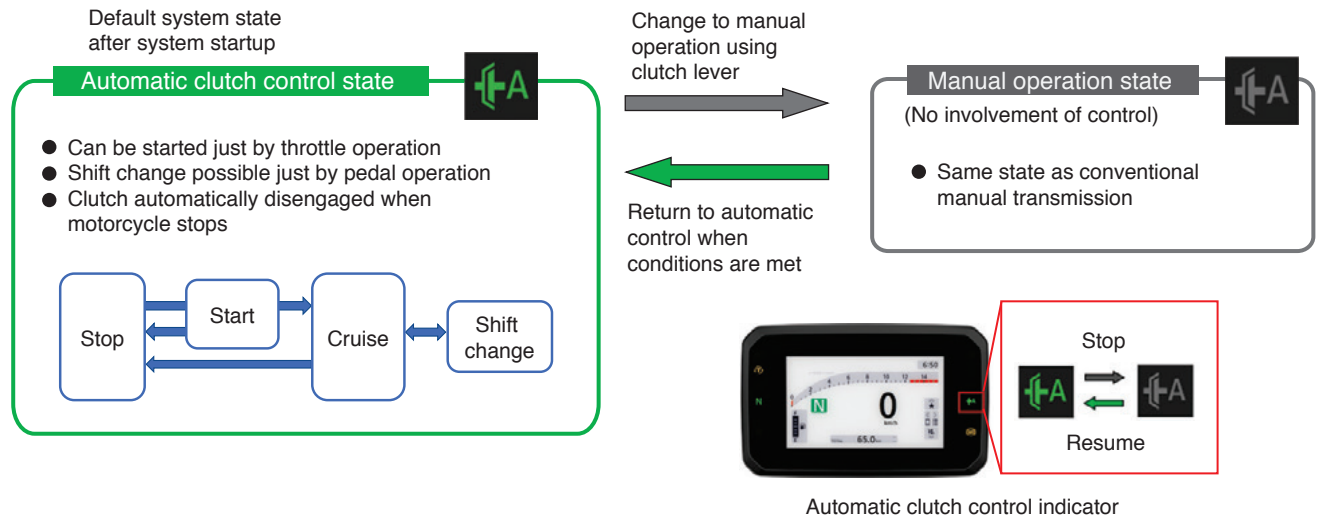


Fig. 8 Operation overview at System ON

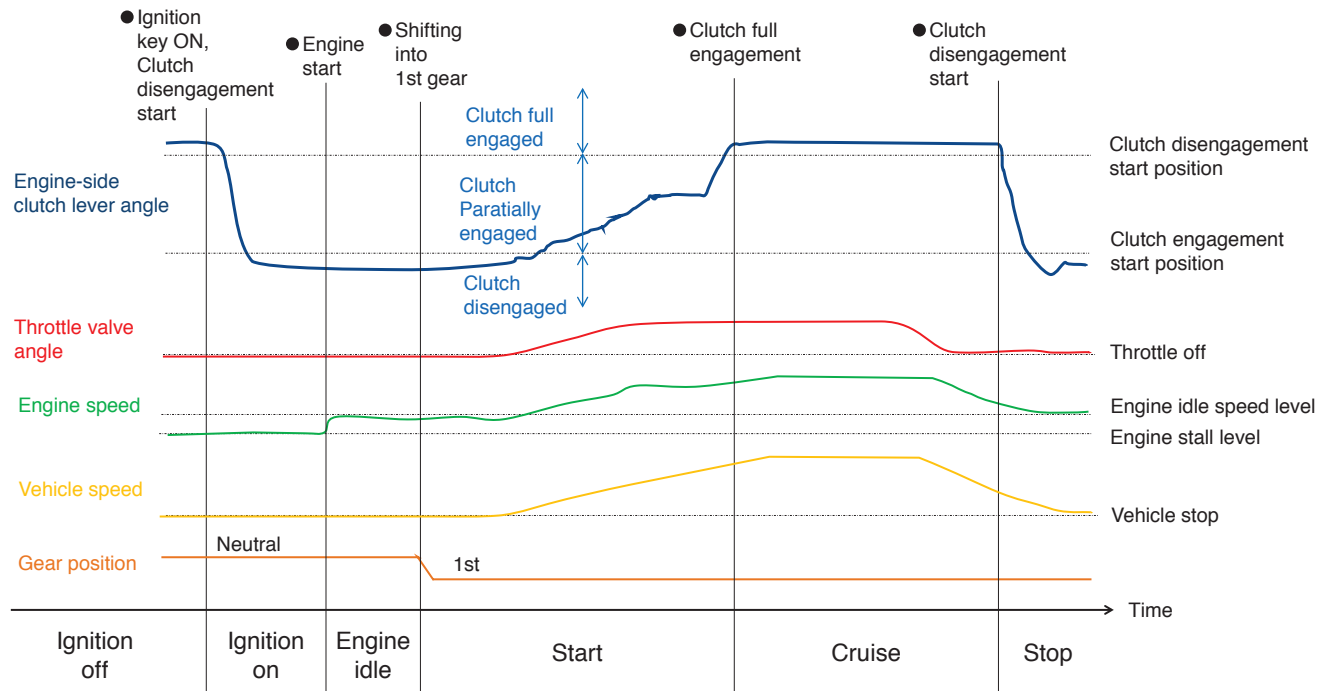


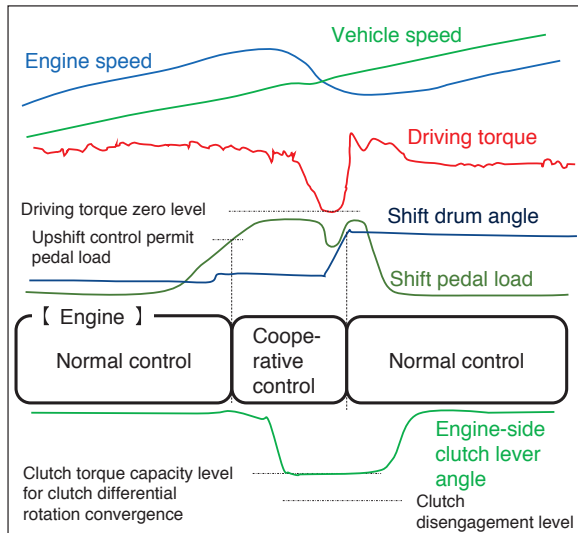
Fig. 9 Transition image of each operation state at ignition on, engine start, starting, cruising, and stopping

The graphs in Fig. 9 show changes of various parameters when starting, cruising, and stopping using the automatic clutch control.

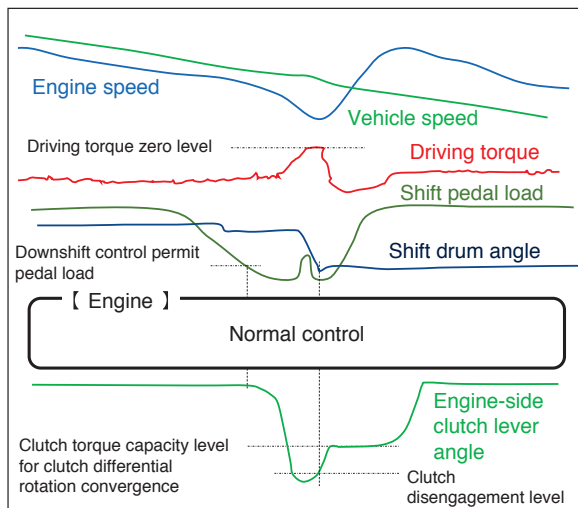
After starting the engine in neutral and shifting to the first gear using only the shift pedal, the rider can start or stop by regulating the throttle and using the brake without using the clutch lever. The system appropriately controls the clutch as indicated by the changes of the angle of engine-

side clutch lever shown by the blue line in Fig. 9 depending on the parameters such as the throttle valve angle, engine speed, and vehicle speed so that the vehicle behavior at the time of starting or stopping becomes linear to rider's input.

The changes of parameters when the gear is shifted only by the shift pedal without using the clutch lever are shown in Fig. 10 taking the shift up during acceleration and the shift down during deceleration as the examples.



(a) Upshifting during acceleration



(b) Downshifting during deceleration

Fig. 10 Operating image at UP, DOWN shifting

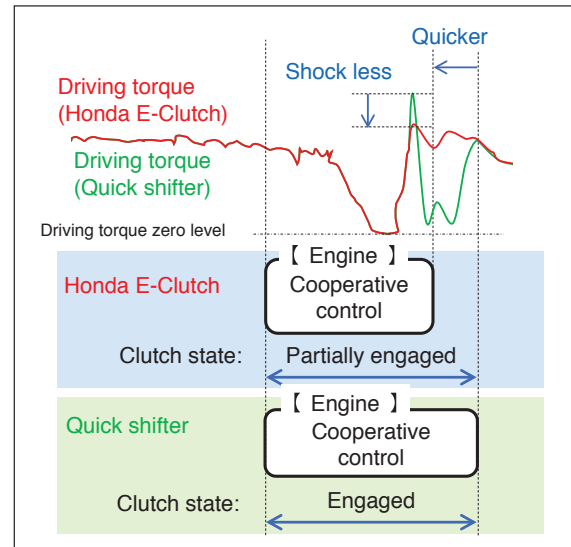


Fig. 11 Comparison of driving force between Honda E-Clutch and quick shifter during upshift

When shifting up during acceleration, the rider's shift pedal effort is detected by the shift sensor just like in the quick shifter, and the system momentarily cuts down the driving force by appropriately controlling the ignition timing and the fuel injection to allow shifting to the next gear. In an ordinary quick shifter, an impact-induced torque (shock) occurs when shifting to the next gear due to the difference of rotating speeds in the transmission gears as Fig. 11 shows. In this system, however, before shifting to the next gear, the clutch is controlled to a partial engagement depending on the engine torque to reduce the torque (shock) occurring at the time of shifting, allowing more smooth shifting than the quick shifter. When shifting down during deceleration, the rider's shift pedal effort is detected by the shift sensor just like when shifting up, and the system disengages the clutch, confirms shifting to the next gear, and synchronizes speeds of the gears by appropriately controlling the partial clutch engagement to allow complete shifting.

Explanations from here on issues rider's manual clutch operations. When the engine is running and one of the gears is selected and the rider grabs the clutch lever, the system detects a manual clutch intervention (rider's manual intervention to the clutch when the automatic clutch control is enabled), and temporarily stops the automatic clutch control. The system identifies a rider's manual clutch intervention from the clutch switch or the load on the actuator motors depending on the conditions of the vehicle. When the automatic clutch control is stopped, the indicator in the meter turns off, and the motorcycle becomes the same as the conventional type equipped with the MT (state of manual intervention). When the operation from the clutch

lever is finished from the said conditions, and the prescribed conditions to be mentioned later are satisfied, or the gear is shifted to the neutral, the automatic mode resumes. Even if the rider unintentionally grabs the clutch lever, and the system turns to the state of manual intervention, the automatic clutch control can be resumed by setting the gear at neutral. With the above-mentioned measures taken, the system permits smooth starting, shifting, and stopping without using the clutch lever as well as allowing resuming to the automatic clutch control requiring no additional operation. As shown in Fig. 12, the motorcycle can be turned to a conventional motorcycle equipped with the MT by disabling the Honda E-Clutch system (System OFF) from the meter.

These functions help the rider to enjoy sportier, easier, and more flexible motorcycle riding.

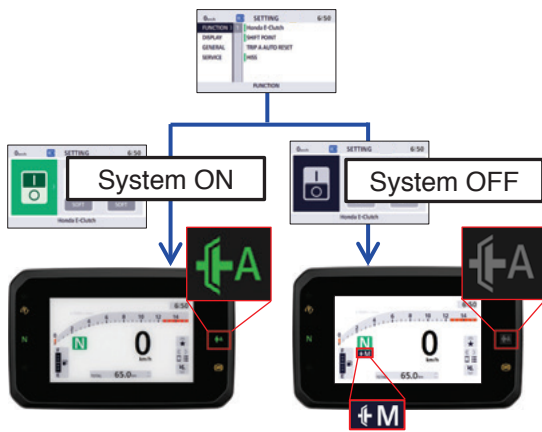


Fig. 12 System ON and System OFF

4. Automatic Clutch Control

The automatic clutch control by directly driving from the motors requires appropriate controls depending on the conditions of clutch. It is also necessary for the automatic clutch control to take into account deviations of various component parts. The clutch control satisfying these two requirements enables smooth starting, shifting, and stopping without using the clutch lever. Explained hereafter is the technical measures for the automatic clutch control.

4.1. Angle Feedback Control and Current Feedback Control Depending on Various Clutch Engagement State

The clutch engagement state can be sorted to the following three types when controlling the clutch by the clutch actuator.

- (1) Engaged
- (2) Partially engaged
- (3) Disengaged

Figure 13 shows the relationship between the engine-side clutch lever angle (control angle), the engine-side clutch lever load (control load), and the torque transmitted by the clutch in each state.

When the clutch is engaged or disengaged, the torque transmitted by the clutch is constant where the changes of engine-side clutch lever load is small. In view of that, the control of position by the clutch lever angle is suitable when the clutch is engaged or disengaged. On the other hand, when the clutch is partially engaged, changes of clutch lever load is large, and as the torque transmitted by the clutch is inversely proportional to the clutch lever load, the control of load by the clutch lever load is suitable. In this system, the clutch lever angle can be calculated by measuring the angle of reduction gear in the actuator using the angle sensor. Accordingly, the control of position using the reduction gear angle (angle feedback control) is employed. The clutch lever load can be estimated by measuring the actuator motor current. We have therefore decided to apply the current feedback control using the motor current for the control of load.

Shifting the above-mentioned control of position to the control of load at the point the clutch engagement state changes such as the disengagement start point and the engagement start point, the clutch control performance has been enhanced⁽³⁾.

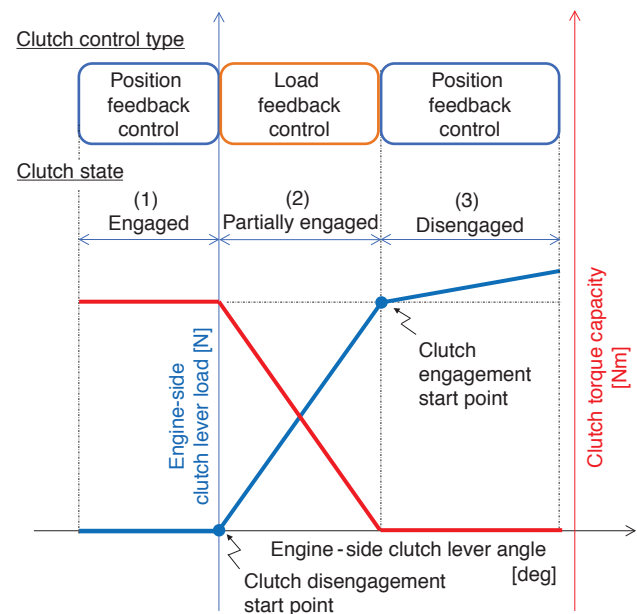


Fig. 13 Relationship between clutch state, engine-side clutch lever angle, and engine-side clutch lever load

4.2. Control of Clutch Considering Deviations of Component Parts

The system needs to control the position and the load

of engine-side clutch lever taking into account the starting positions of disengagement and engagement and the motor current (load on the clutch lever) at these positions. Such a position and current differ due to the deviation of each component part and/or the characteristics of electrical part. To realize appropriate clutch control, it is necessary to compensate for the deviations that differ from a vehicle to another. In this system, the MCU learns in each vehicle the starting positions of disengagement and engagement, the friction current of unloaded motor, and the current at the engagement position, and compensates the deviations. The system learns the starting position of disengagement by detecting the changes of working speed resulting from the changes of load when the actuator turns in the direction of disengagement from the clutch lever angle when in the engaged area. Similarly, the system learns the starting position of engagement by detecting the changes of working speed resulting from the changes of load when the actuator turns in the direction of engagement from the clutch lever angle when in the disengaged area.

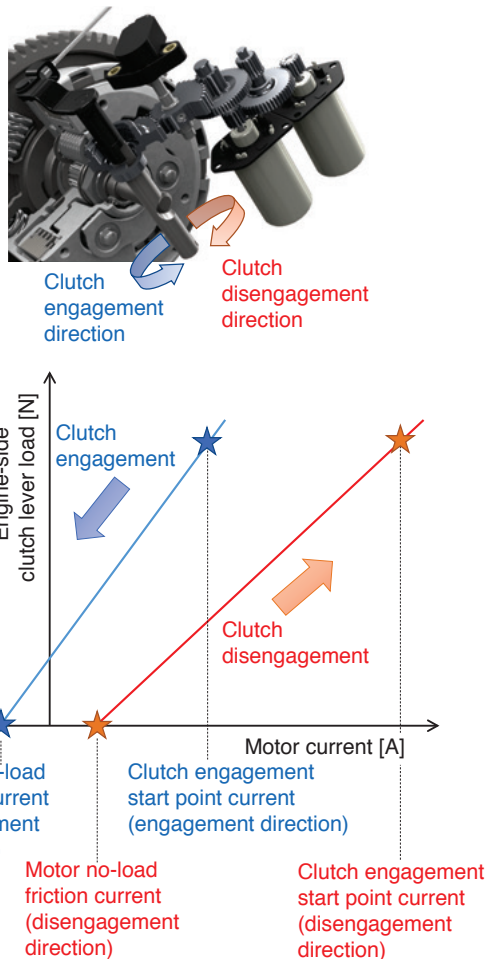


Fig. 14 Relationship between engine-side clutch lever load and motor current

Figure 14 shows the relationship between the engine-side clutch lever load and the motor current.

The relationship between the engine-side clutch lever load and the motor current is not a simple one-to-one correspondence, but differs depending on the direction of actuator motion. That is because the motor brush friction and the direction of friction occurring in the reduction gear differ depending on the direction of motion. We have therefore devised the system to learn the friction current of unloaded motor and the current at the starting position of engagement from the current occurring at each position when the actuator is operated. In the current values that the system has learned, the working directions of engagement and disengagement are taken into account^{(4), (5)}.

By learning the above-mentioned positions and current values, various deviations of component parts in mass-production vehicles are compensated, realizing the automatic clutch control directly driven from the motors.

5. Judgment of Manual Clutch Intervention and Resuming to Automatic Clutch Control

For a temporary discontinuation of automatic clutch control when the clutch is manually operated (intervened), the manual clutch operation needs to be identified accurately. When resuming the automatic clutch control from the manually-intervened condition, the resuming needs to take place without strangeness for the rider. The system appropriately identifies vehicle conditions and rider's use of clutch, allowing the rider to choose the automatic clutch control or the manual clutch operation. How they are identified is explained hereafter.

5.1. Identification of Manual Clutch Intervention

While the automatic clutch control is temporarily discontinued when manually intervened, the clutch may engage abruptly if the intervention is incorrectly identified. It is necessary to reduce abrupt changes of reaction force on the clutch lever or vehicle behavior by an accurate identification of manual clutch intervention. Figure 15 shows how the intervention is identified. When engaged as in (1), as the clutch actuator is not actuating the clutch, there is no change of clutch condition or vehicle behavior even if the clutch control is temporarily discontinued. When in the condition (1), therefore, an intervention is identified by the clutch switch attached to the left hand clutch lever. When partially engaged (2) or disengaged (3), as the clutch is operated by the clutch actuator, even more accurate identification of manual clutch intervention is necessary. The manual clutch intervention during the automatic clutch control is identified by detecting a shift of the load on the engine-side clutch lever to rider's input from the left hand clutch lever from the changes of clutch control angle (reduction gear angle) and motor current.

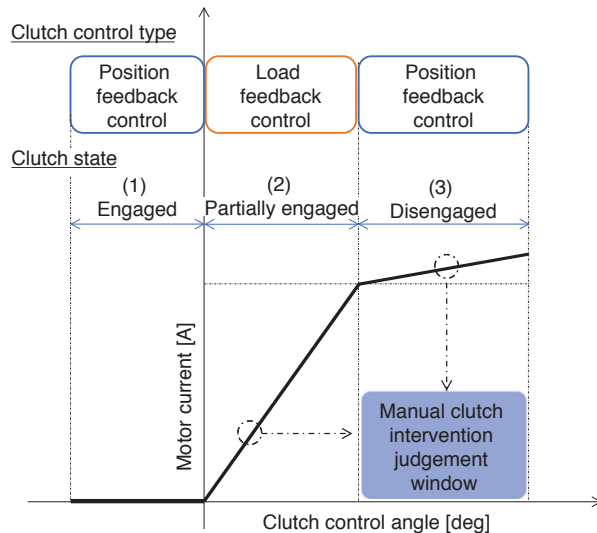


Fig. 15 Manual intervention operation judgment during automatic clutch control

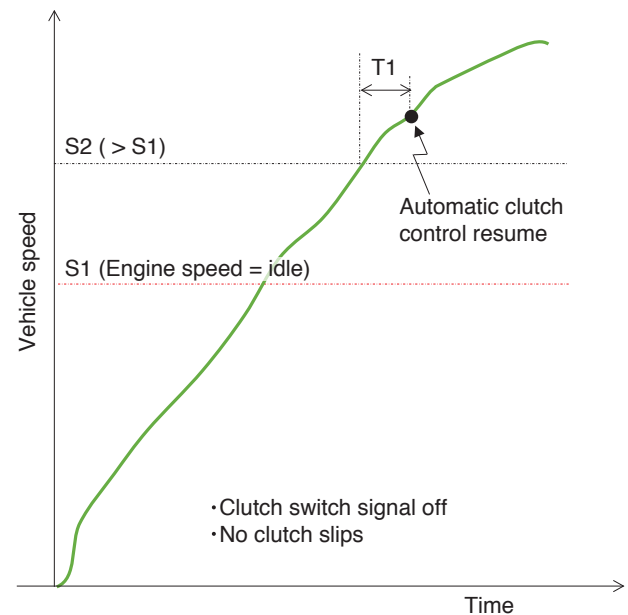
When manually intervened from partially engaged (2) or disengaged (3) condition, the control of load by the actuator turns to rider's input from the left hand. The actuator's clutch control load lowers when manually intervened, and eventually falls in the manual intervention judgement window in Fig. 15. Upon confirmation of the clutch control load surely fallen in the manual intervention judgement window, the system identifies that a manual clutch intervention taking place. Employing the judgement measure for various conditions, we have realized such a method of manual clutch intervention judgement free of strangeness to the rider such as changes of reaction force on the clutch lever or vehicle behavior⁽⁶⁾.

5.2. Resuming Automatic Clutch Control after Manual Clutch Intervention

When the rider finishes manual clutch intervention, it is necessary to resume automatic clutch control at a right timing. When the automatic clutch control is resumed, the system may disengage the clutch depending on the vehicle conditions (such as vehicle speed and engine speed). We have therefore employed the three resuming patterns to adjust to the vehicle conditions as in Fig. 16.

The pattern A shown in Fig. 16 (a) is when the vehicle speed is adequately higher above the idling vehicle speed after completion of the manual clutch operation. (The idling vehicle speed is the speed when the clutch is engaged and the engine speed at idling.) Under these conditions, the clutch is engaged as well when in the automatic clutch control. Since no change occurs in the vehicle behavior under the said conditions, the system resumes the automatic clutch control in a short period of time. In the pattern B shown in Fig. 16 (b), although the vehicle speed is such

that the clutch is disengaged when in the automatic clutch control, if the automatic clutch control is resumed instantly under such conditions, the clutch may be disengaged, the traction may change abruptly causing sudden changes of vehicle behavior against rider's expectation. To deal with this issue, a standby period longer than that in pattern A is provided and only after the vehicle conditions have been settled, the system resumes the automatic clutch control. The pattern C shown in Fig. 16 (c) is such a pattern of resuming automatic clutch control that is intended to provide assistance for prevention of engine stall when the brake is operated without grabbing the clutch lever when standing by for resuming of automatic clutch control in the pattern B. When the rider is grabbing the clutch lever and the vehicle speed does not reach the idling vehicle speed as shown in Fig. 16 (d), the system does not resume the automatic clutch control. As such, by employing such a system configuration that resumes automatic clutch control at an appropriate timing depending on the vehicle conditions after completion of a manual clutch operation, we have realized the automatic clutch control free of strangeness and erratic vehicle behavior⁽⁷⁾.



(a) Pattern A

6. Conclusion

The Honda E-Clutch system has been developed by adding the clutch actuator, the MCU, and the shift sensor to the basic motorcycle having a MT. The appropriate clutch control has been realized by the selection of clutch control method according to the clutch engagement state along with the automatic compensation by the learning of system deviations of component parts. The automatic clutch control free of strangeness has been realized by the identification of manual clutch intervention depending on the conditions of clutch and the resuming of automatic clutch control depending on the vehicle conditions after completion of the manual operation.

With this system employed, it is now possible to start, shift the gear, and stop without grabbing the clutch lever, allowing the rider to concentrate more on the riding. At the same time, the rider can choose conventional manual clutch operations when the rider wants it. This allows the rider to enjoy sportier riding by the automatic clutch control without forcing the rider to change their riding habits. It further permits to avoiding operations that could become undesirable in certain situation and makes the riding easier by taking advantages of the AT.

This system has minimal restricting factors for mounting and is applicable to existing engines. As the increase of weight from addition of the new system is only 2 kg and its influence on the complete motorcycle is minimal, this system is applicable to various types of vehicles. We would like to extend the new system so that it becomes a standard of FUN motorcycles and more customers enjoy such products. In the future, we would like to further enhance this technology and contribute to expansion and advancement of entire motorcycling activities.

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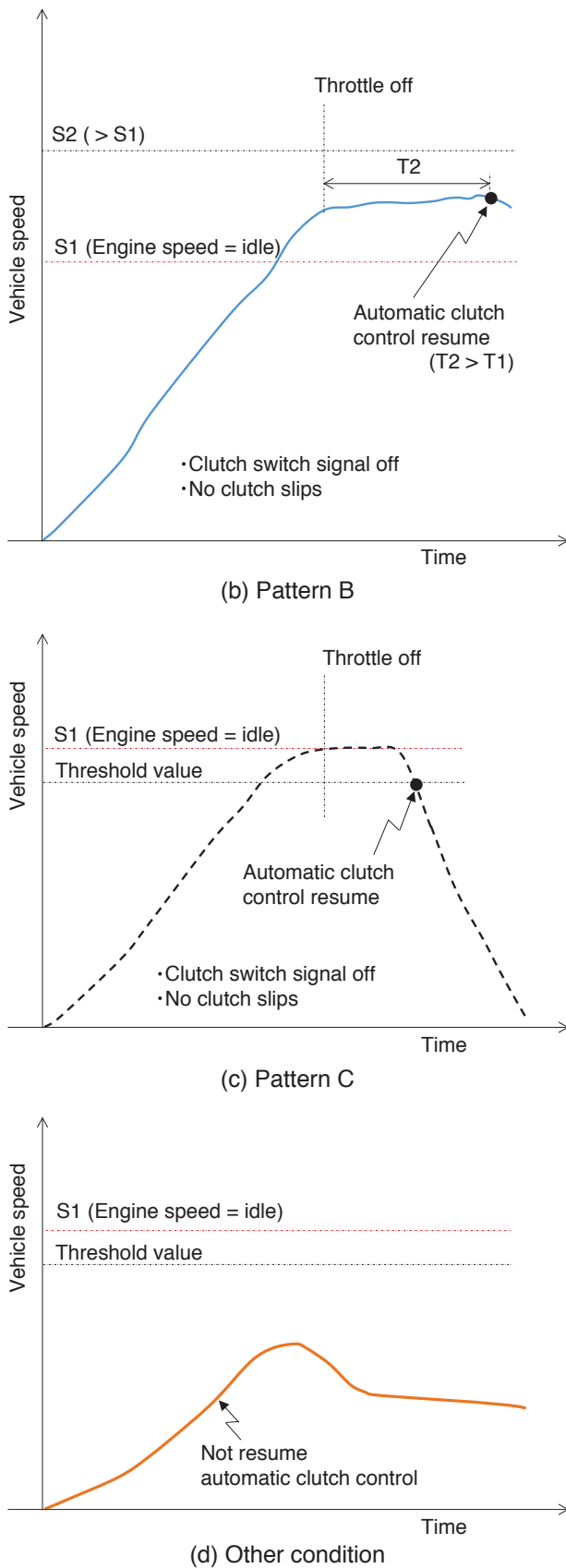


Fig. 16 Resume pattern of clutch automatic control state depending on vehicle state