

Development of Electronically Controlled Belt CVT “Honda S MATIC” for Motorcycles

Michio ASUMI*
Kazuhiko MORI*

Hideo ISHIKAWA*
Naotada MATSUDAIRA*

ABSTRACT

World's first electronically controlled belt CVT System (hereinafter referred to as Honda S MATIC) for 250 cm³ class scooters has been developed in FORZA 2004 model. Honda S MATIC employed a rubber belt with a high friction coefficient and pulleys made of aluminum alloy. It was placed inside the unit-swing type engine, which is the same type as conventional scooters. For shift changing, pitch circle diameter of the driving pulley was adjusted by a motor. Preparing several selectable shift modes, suitable shifting characteristics could be obtained at flat road or mountain road. Furthermore, because of the elimination of ratio change due to aging, Honda S MATIC provides several advantages such as little reduction in maximum speed, no change in shifting characteristics, and no change in clutch connection point. Exceeding the conventional CVTs, Honda S MATIC has simultaneously satisfied low fuel consumption, low emissions, low noise and excellent engine performance.

1. Introduction

Demands for reduction in exhaust emissions, lower fuel consumption, and low noise, which offer a feeling of superior quality, are growing year after year, as part of the measures to cope with global environmental issues. Some of these demands tend to be in direct conflict with enhancing the power performance. The conventional belt CVT had its limitation in that it was capable of only one shifting characteristic. The electronically controlled belt CVT system (hereafter called "Honda S Matic system") capable of setting shifting characteristics freely, was developed in response to these demands. The engine equipped with the Honda S Matic system is an unsprung unit swing type engine similar to the engine in conventional scooters, and is designed as a lightweight and compact engine without reducing its maneuverability.

This paper describes the technology of the Honda S Matic system used in the 2004 year model FORZA 250-cm³ class scooter.

2. Conventional Belt CVT Technology

The belt CVT with a good overall balance of weight, performance, and cost has been used in scooters with the goal for realizing easy-to-drive performance. Figure 1 shows the structure of the conventional belt CVT. The conventional belt CVT generates centrifugal force in the weight roller of the drive shaft because of engine rotation, and converts this force to thrust force that acts to move the movable drive face in the axial direction. The belt pitch diameter changes and shift change occurs according to the balance between the thrust force on drive pulley, the spring load of driven pulley, and the thrust force on driven pulley generated by the torque cam. The shifting characteristics were decided primarily by these mechanical elements, and to freely set the ratio corresponding to each throttle opening was a challenging issue. Although low engine speed is beneficial to achieve exhaust emissions reduction, low fuel consumption and low noise, the power performance decreases.

* Asaka R&D Center

When the travel distance increases, the belt wears and the belt width decreases. As a result, the pitch diameter of drive pulley becomes small, the pitch diameter of driven pulley becomes large, and the ratio changes over to the low speed range, therefore, the maximum speed decreases.

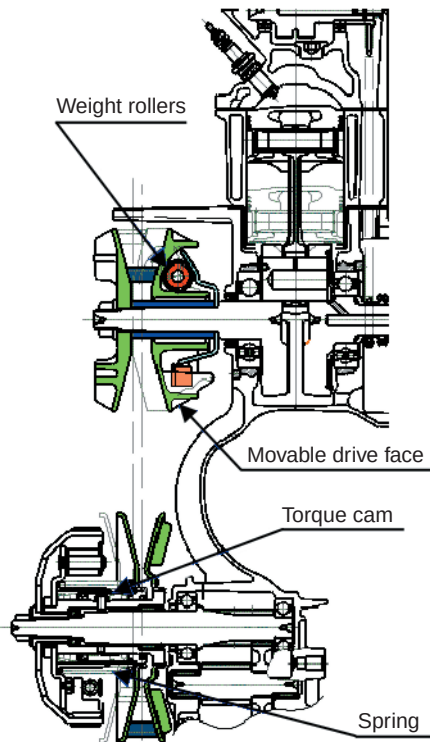


Fig. 1 Structure of conventional belt CVT

3. Basic Structure and Requirements for Development Goals

The goals of development of the Honda S Matic system are as follows.

- (1) To achieve lightweight and compactness
- (2) To enable shifting characteristics that fuel consumption, exhaust emissions, and low noise are compatible with driveability.
- (3) To adopt a simple operation system.

In the 2004 model FORZA, three modes are provided including two automatic modes and one manual mode. The rider can press the switch and freely select the desired mode. This arrangement contributes to a fun to ride. Figure 2 shows the overview of this system. Various sensors are provided for detecting drive speed, driven speed, pulley position, vehicle speed, and throttle opening. The ratio control unit decides the control objectives from the data from these sensors and switches, and it controls the pulley position by the motor drive based on these data. Figure 3 shows the cross section of the S Matic mechanism. Figure 4 shows the shift change mechanism on the drive side.

The control current flows into the motor, which rotates and transmits the torque to the movable gear through the reduction gear. The internal part of the movable gear contains a feed screw, which converts the transmitted torque to axial force, moves the movable drive face, and performs the shift change. The guide key is used as the mechanism that transmits the engine torque while the movable drive face slides. Because the shift change drive unit is not lubricated, a plastic gear was used in a part of the unit considering both gear wear reduction and weight reduction. The guide key and the feed screw are lubricated by grease to ensure their moveability.

Outside air is introduced to lower the temperature in the belt chamber considering the belt durability. Measures to prevent intrusion of water or dust have also been adopted. The structure on the driven side is basically similar to that of the conventional belt CVT, but a rotor for detecting the pulley speed has been provided

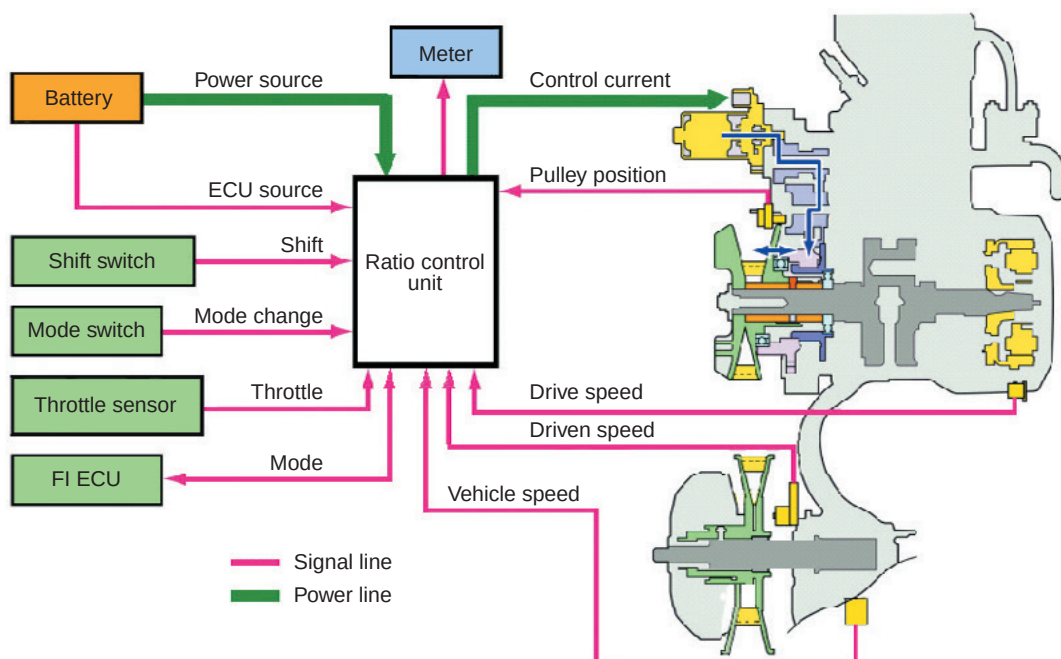


Fig. 2 Diagram of Honda S Matic system

additionally. The scooter generally has an unsprung unit swing type engine, but since the engine weight affects the maneuverability adversely, a lighter weight engine is desired. To maintain the compact and lightweight features, which are the advantages of the conventional belt CVT, rubber belt was used and the pulley was made of die cast aluminum alloy. The movable drive face consisted of the boss made of steel and cast into the aluminum alloy pulley with the pitch diameter restricted to a small value to obtain a wide ratio.

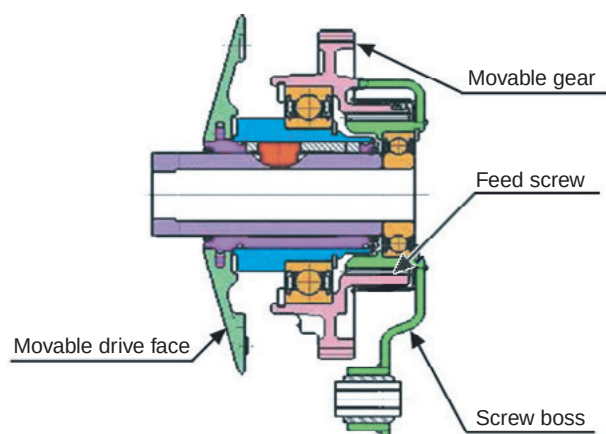


Fig. 4 Shift mechanism of drive side of Honda S MATIC

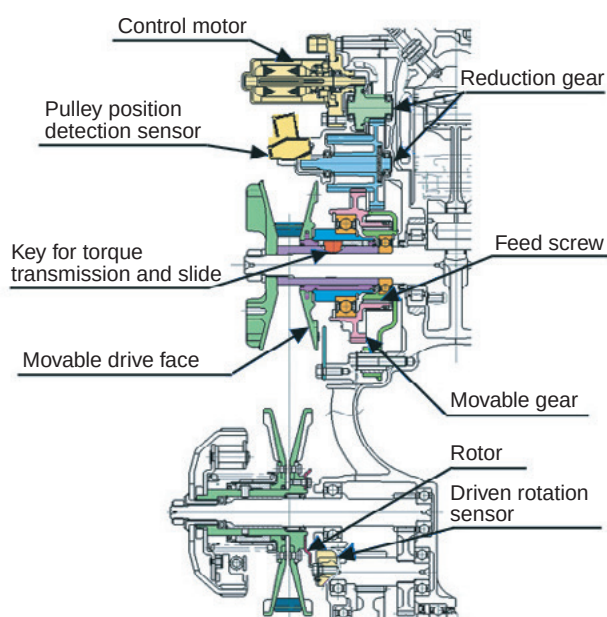


Fig. 3 Sectional view of Honda S MATIC mechanism

4. Setting of Specifications for Each Part and Performance

4.1. Selection of Drive Belt Suitable for Ratio Control

The material of the drive belt, which is a rubber belt with a high coefficient of friction and lightweight, is essential to achieve light weight and compactness. However, the slip ratio of the conventional rubber belt is large. Because the difference in ratio between no load and full load is very large, it was important to minimize the slip ratio of the rubber belt to ensure ratio control in the Honda S Matic system. Table 1 shows the comparison of the drive belts of the 2000 model FORZA and the 2004 model FORZA. Figure 5 shows the external view of the drive belt.

As shown in Table 1, the drive belt of the 2004 model FORZA were enhanced mainly three points shown below.

- (1) Change in the cog shape: Change from a single cog to a double cog

Table 1 Comparison of drive belt specifications

		2000 Model FORZA	2004 Model FORZA
Material of component	Upper canvas	Cotton canvas	Without canvas
	Upper rubber	Chloroprene rubber with thread	Chloroprene rubber with thread*
	Core wire	Polyester	Aromatic polyamide
	Bonding rubber	Chloroprene rubber	Chloroprene rubber
	Lower rubber	Chloroprene rubber with thread	Chloroprene rubber with thread*
	Reinforcements	With reinforcement	Without reinforcement
	Lower canvas	Polyamide canvas	Synthetic fabric mixed cotton canvas
Shape	Cog shape	Single cog	Double cog
	Upper width	Approximately 23 mm	Approximately 25 mm
	Thickness	Approximately 10.5 mm	Approximately 12.5 mm
	Angle	Approximately 30 degrees	Approximately 30 degrees
Ratio range		2.95	3.13

* : New compounded rubber which has two times strength of rubber elasticity rate for single cog

- (2) Change in the core wire: Change from polyester to aromatic polyamide
- (3) Change in the upper and lower rubbers: Change to compounded rubber with enhanced lateral pressure strength

Figure 6 shows a comparison of slip ratio of the drive belt in the typical LOW ratios and TOP ratios. In the 2000 model FORZA, the slip ratio in the LOW ratio of the single cog belt is more than approximately 8%, and the slip ratio in the TOP ratio is more than approximately 2%. Compared to the 2000 model FORZA, the pitch diameter for LOW ratio on the drive pulley of the 2004 model FORZA is reduced, and the ratio range has been widened by approximately 10%. Therefore, it is inappropriate for reducing the slip ratio. However, by using new forms of belt composed of new materials, slip ratios of approximately 4.5% in the LOW ratio and approximately 1% in the TOP ratio have been obtained, and realized a belt suitable for ratio control.

4.2. Shift Control

The 2000 model FORZA employs a belt CVT (Hyper V Matic system). By changing the shift change timing to two stages, the connection from the medium-speed area to the high-speed area has been enhanced compared to previous models of the scooter.

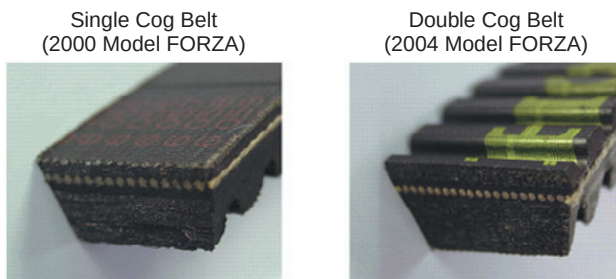


Fig. 5 External view of drive belt

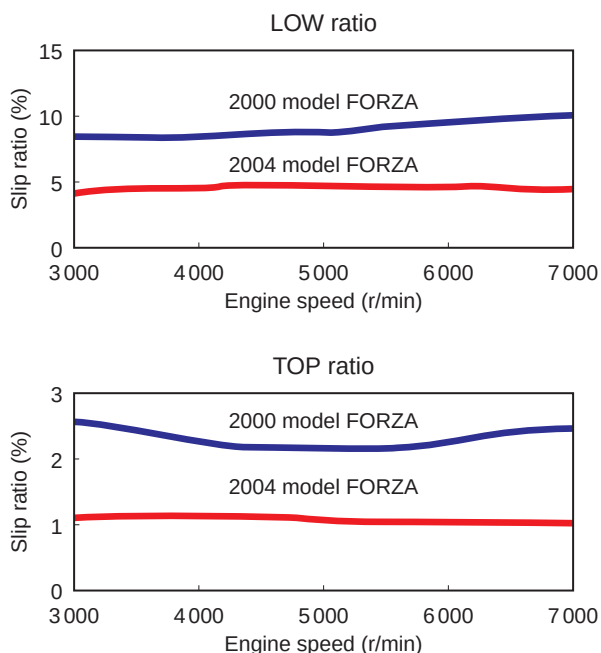


Fig. 6 Comparison of slip ratio of drive belt

As the result, comfortable driving performance was obtained by smooth acceleration. Figure 7 shows the shifting characteristics.

Furthermore, by setting the automatic D mode and S mode, and the manual M mode shifting characteristics in the 2004 model FORZA, the range of usable engine speeds increased, and smoother running was realized. The features of each mode are described below.

(1) D mode

In the D mode, engine speed in the shift area was lowered, and fuel consumption, exhaust emissions and noise enhanced. For obtaining smooth acceleration, the shift area adopted characteristics of which engine speed increases in conjunction with increase of vehicle speed. Figure 8 shows the shifting characteristics. In the D mode, the ECE40 mode fuel consumption was enhanced by approximately 10% compared to the 2000 model FORZA. In exhaust emission levels, half in CO and less than one-third in HC of the regulation value in Japan were attained. Figure 9 shows the fuel consumption and exhaust emission data during the D mode driving. Low noise characteristics were enhanced compared to the 2000 model FORZA by reducing the engine speed at partial throttle opening.

(2) S mode

The shift area in the S mode also adopted characteristics of which engine speed increases in conjunction with increase of vehicle speed, as well as D mode. As shown in Fig. 10, the LOW ratio in S mode for shifting characteristics has been set larger than that in the D mode. As a result, the acceleration performance has been enhanced, as shown in Fig. 11, compared to that of the 2000 model FORZA. By setting the ratio to a lower speed during deceleration, the engine braking effect can be obtained compared to that of the conventional scooter.

(3) M mode

As shown in Fig. 12, the M mode is a manual mode that enables six shift ratios to be fixed. The rider can freely select a fixed ratio, thus acceleration during hill climbing and also during high-speed running was enabled easily. Engine braking can also be used by shifting to low gear.

Considering ease of use for riders, the automatic shift down and shift limitation functions have been provided. The automatic shift down is a function that enables automatic shift to a proper low gear ratio for comfortable running at low vehicle speeds. It helps eliminate the uncomfortable feeling in riders. The shift limitation function has two functions for restricting the shift down and the shift up by riders. When the rider attempts to shift gear in the condition which driving comfort will be lost, this function does not permit the shift. The LCD part of the meter flashes to notify the user that the shift operation has been restricted.

4.3. Ratio Change

Even if the belt or the pulley surface wears out, the pulley position is changed proportionally and control is performed such that the ratio becomes equal to the preset ratio. As the result, the belt pitch diameter does not change, and the ratio does not change provided there is some margin in the range of pulley operation.

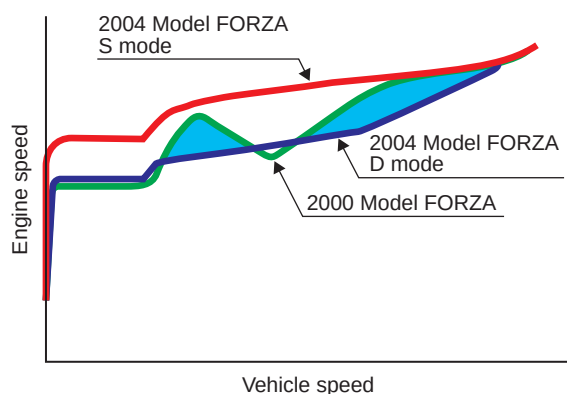


Fig. 7 Shift speed characteristics of HYPER V MATIC system

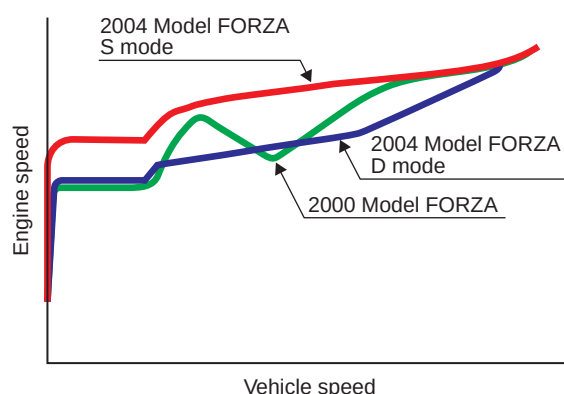


Fig. 10 Shift characteristics of S-mode

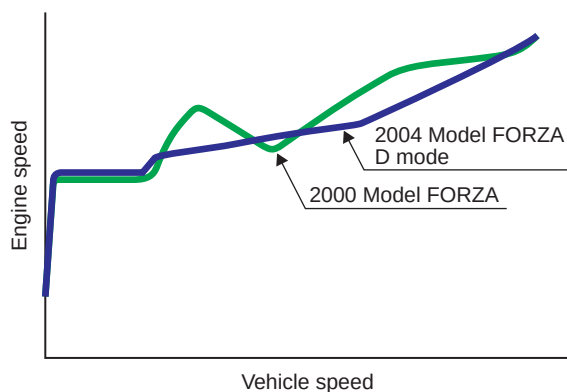


Fig. 8 Shift characteristics of D-mode

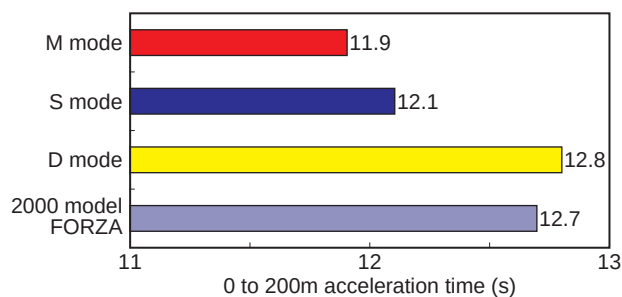


Fig. 11 Comparison of acceleration performances

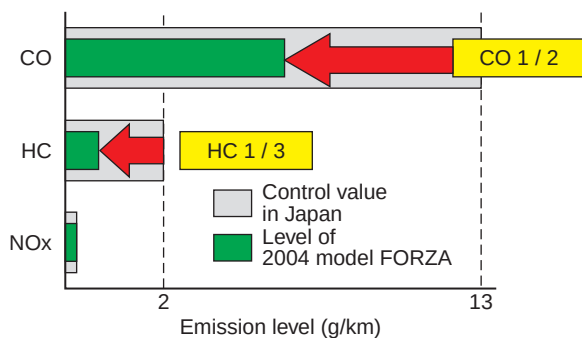
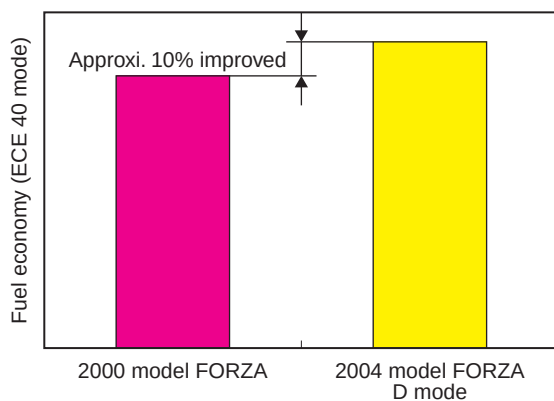


Fig. 9 Fuel consumption and exhaust emission during D-mode use

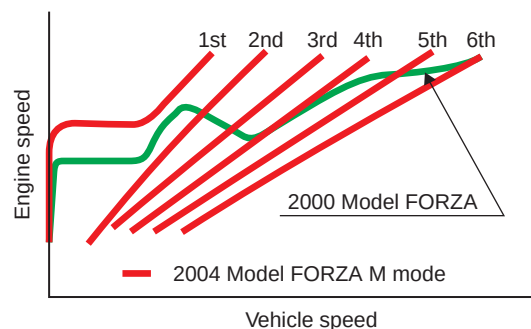


Fig. 12 Shift ratio of M-mode

4.4. Control Specifications

4.4.1. Overview of control

The basic primary control flow starts with the calculation of target drive rotation from the throttle opening, its displacement speed, and the driven rotation. Next, the difference between this value and the present drive rotation is calculated. The electric current control for the motor is implemented after deciding the motor control command value from this difference. The indicator lamp of the meter lights up to indicate the specific shift change mode, and the shift position during the M mode is also shown in the LCD display.

Optimized fuel injection and ignition controls are implemented to suit the aims of each shift change mode. Therefore, the function of notifying the FI ECU the present shift change mode from the ratio control unit is also provided. A pulley position sensor is also used to identify the movable range of the drive pulley. Figure 13 shows the overview of the control system.

4.4.2. Selection of shift mode

When selecting the shift mode, for instance, when changing over from D mode to S mode resulting in an abrupt ratio change, a noticeable speed change shock is generated. To help eliminate such shocks, the ratio control unit performs control so that the ratio is changed gradually and smoothly during mode selection. Figure 14 shows the overview of control during shift mode selection.

4.4.3. Change from automatic to manual mode

The function of automatic selection of optimum ratio is provided when changing over from D mode or S mode to M mode.

4.5. Honda S Matic Control Switch

Controls such as switch, levers, and pedals are normally operated close at hand or close at foot, but the switches for controlling the Honda S Matic have all been arranged on the handlebar close at hand considering operability and comfort near the foot.

Switches required for operating the Honda S Matic include the push button mode switch for selection of "Automatic and Manual" modes, the see-saw type shift switch for "High or Low Gear" during the M mode and for selection of the "D Mode and the S Mode." This arrangement of switches easily brings out the appeal of the Honda S Matic System. Figure 15 shows the operation when a switch is pressed.

The arrangement of the switches is such that they are always in the field of view of the rider during driving. The shift switch is arranged on the left side considering ease of operation simultaneously with the right hand throttle operation. As shown in Fig. 16, the mode switch is arranged on the right side considering the balance of operation with the shift switch. This arrangement enables ease of operation of the S Matic switches without losing the ease of operation of existing switches such as the direction indicator switch. It has also enabled the external form of the handle switches to be made the same size both on the left and right sides, thereby enhancing the design around the handle grip.

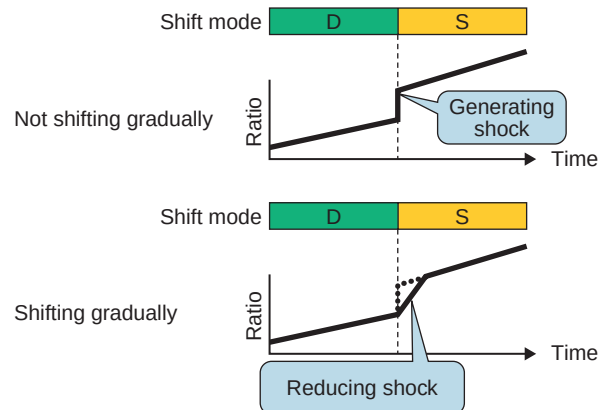


Fig. 14 Control concept of shifting modes

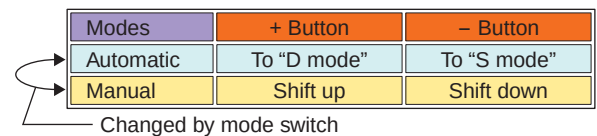


Fig. 15 Explanation of shift switch operation

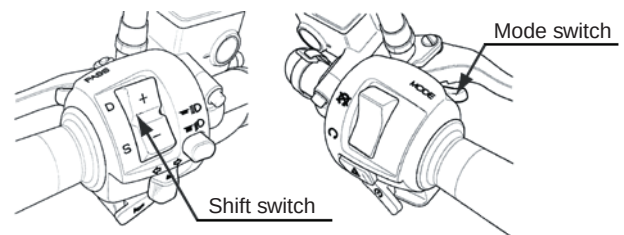


Fig. 16 Location of shift switch

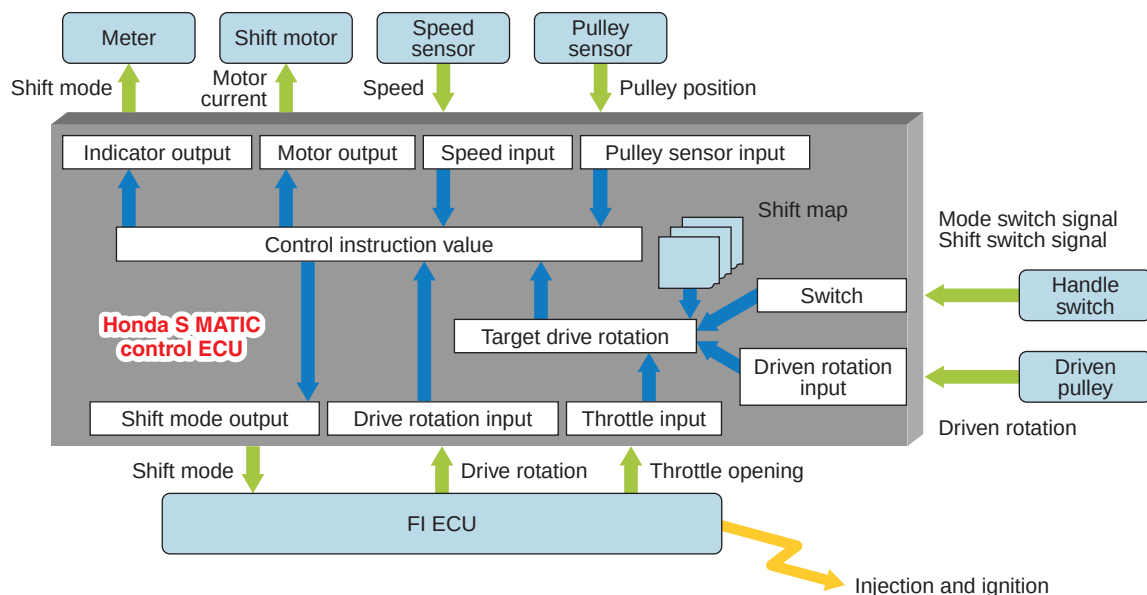


Fig. 13 Diagram of Honda S Matic control flow

5. Conclusion

A lightweight electronically controlled belt CVT system was developed for use in the unsprung unit swing type engine of the same type as used in conventional scooters.

- (1) Riders can select shifting characteristics according to the condition by setting any of the two automatic modes for electronic control of the belt type CVT, thereby realizing a good balance between fuel consumption, exhaust emissions, low noise on the one hand and power performance on the other hand.
- (2) Acceleration performance and engine braking performance not available in conventional scooters have been achieved by providing a manual mode that can fix the shift change ratio.
- (3) A simple and easy-to-operate system was developed enabling selection of running mode and shift operations to be performed easily and close at hand.

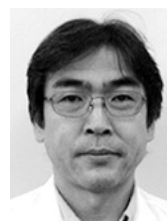
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■ Authors ■



Michio ASUMI



Hideo ISHIKAWA



Kazuhiko MORI



Naotada MATSUDAIRA