

Development of 5-speed Dual-clutch Transmission System for All-Terrain Vehicle

Kinya MIZUNO*

Seiji HAMAOKA*

Eiji KITTAKE*

Masaki KOBAYASHI*

ABSTRACT

A dual-clutch transmission, Honda's first, has been developed for use in utility All-Terrain Vehicles (ATVs). The developed system targeted a comfortable ride and fuel economy while maintaining the off-road running-through performance typical of an ATV, by leveraging the aspect of the transmission efficiency of a dual clutch transmission being equal to that of a manual transmission. This system was developed without changing the transmission axis configuration, the locations at which the clutch and change gear are attached, or other basic elements of the layout, based on the engine being equipped with a manual transmission. The gearshift system was kept simple by adapting a motor-driven gear shift system and simplifying the hydraulic changeover circuit so that the number of operating devices could be held to a minimum. These features also allowed the developed transmission to be mounted on the same frame as that of the manual transmission vehicle.

1. Introduction

ATVs are used in a broad variety of applications, ranging from agriculture and stock farming to trail riding and hunting. ATVs are also driven by a wide variety of people, ranging from experienced users who are used to ATVs to novices who are unaccustomed to gearshift operation. Therefore, there is increasing demand among users for an easy ride, with a trend toward replacing manual transmissions with automatic systems. Meanwhile, the lower fuel consumption of manual transmission vehicles is being reassessed in view of measures to address global environmental issues.

Honda has sought to make the previous kind of manual gear shifting operation easier by developing a motorized gearshift (the Electric Shift Program, or ESP) in which the gear shifting movement is performed by a motor⁽¹⁾, a torque converter type 3-speed automatic transmission⁽²⁾, and a hydraulic-mechanical transmission (HMT)⁽³⁾, and marketing ATVs equipped with these various systems. Other manufacturers are selling ATVs equipped with belt-type CVTs. Table 1 presents a comparison of automatic mechanisms used in previous ATVs.

The issues ordinarily faced with automatic transmission mechanisms include diminished transmission efficiencies because of slippage or flexing resistance in the transmission mechanism, together with the resulting reduction in running through performance, diminished drive feeling accompanied by a sense of slippage, and reduced fuel economy. There was demand, therefore, for development of a new gearshift system that realizes an easy ride while also overcoming these automatic transmission issues.

On the other hand, from the perspective of product development, manual transmission vehicles and conventional automatic transmission vehicles are different greatly in their construction methodologies. Therefore, the parts employ different engineering design principles, and in some cases even the frame has to be reconsidered. Due to these issues, it is desirable for the two types of vehicles to have as many commonized parts amongst them as possible.

Given this context, a dual-clutch transmission system integrated with the engine was developed for use in ATVs. This paper will describe the construction of the developed system and its technological features.

* Motorcycle R&D Center

Table 1 Transmission categories for ATVs

Categories	Typical ATV	Merits	Demerits
Electric shift program (ESP)	Honda TRX420FM	The same basic construction as manual transmission The same off-road ability as manual transmission	Manual shift only Necessity for start clutch
Torque converter with 3AT	Honda TRX680FA	Mechanical control for start Smooth start and shift	Completely different in construction Lower transmission efficiency due to torque converter Necessity for shift device each gear
Hydraulic-mechanical transmission (HMT)	Honda TRX500FA	Smooth driving and low vehicle behaviour due to gear shift	Completely different in construction Lower transmission efficiency due to HFT Necessity for start device Lower capacity for transmission
Belt converter	Other	Smooth driving and low vehicle behaviour due to gear shift Lower in cost	Completely different in construction Unsuitable for ATV's usability Lower transmission efficiency due to belt converter Necessity for start device Lower capacity for transmission

2. Development Goals

The dual-clutch transmission system was developed for the automatic transmission version of the mid-class TRX420 series, with 420-cm³ displacement, which already had a line-up of manual and motorized gearshift vehicles. The developed system had the engine and transmission integrated so as to fit completely within a single casing. This is the same construction as general ATVs or motorcycles.

An automatic transmission for ATVs should provide running through performance equal to that of vehicles with manual transmissions while not giving riders undue shift shock or driving power reduction. It is particularly important to make certain that there is no reduction in the driving power when riding up a steep gradient, leaving the vehicle with insufficient climbing power.

It is characteristic of the dual-clutch transmission that the transmission elements are the same as in a manual transmission, for it to obtain equal transmission efficiency, as well. It is also known that reduction of driving power can be precluded by adjusting the shift from one clutch to the other when shifting gears. A dual-clutch transmission was therefore adopted with the goal of realizing an easy ride, while also providing running through performance and enhanced fuel economy relative to previous ATVs with automatic transmission, including hydraulic-mechanical transmission.

On the other hand, certain issues have been pointed out: When standing start control is used with a dual-clutch, a stable standing start control system is needed. Construction of the dual-clutch unit becomes complicated so that the size of the transmission needs to be reconsidered. The transmission section needs a large number of sensors and gearbox parts⁽⁴⁾. Also, automatic gear shifting may generate undue noise from operation of the gearbox.

The goals of the present development project were

therefore defined as follows:

- (1) The transmission should be mountable on the frame of an existing series vehicle without changing the shaft arrangement or the locations of the clutch and change gear from the manual transmission model.
- (2) The system should be made simple and lightweight.
- (3) Shift shock should be on par with those of previous vehicles using automatic transmissions with torque converters.
- (4) The transmission mechanism should not generate undue mechanical noise during automatic gear shifting.

3. Overview of the Dual-clutch System

An ATV equipped with the developed dual-clutch transmission is shown in Fig. 1, and its engine is shown in Fig. 2. The overall system configuration is shown in Fig. 3. The driving power of the engine is conveyed through the centrifugal-type starting clutch and primary gear to the dual-clutch transmission, and is transmitted through the transmission to the output shaft.

Both of clutches are connected with the gearbox. The first clutch controls the odd gears (first, third, and fifth) while the second clutch controls the even gears (second



Fig. 1 Appearance of TRX420FA

and fourth) and reverse. The gear shifting method is similar to that in the dual-clutch transmission on an automobile. The gear of the non-driven clutch side is prepared in advance to the targeted gear by gearbox. Switching between the driven clutch and the non-driven



Fig. 2 Appearance of engine

clutch completes the gear shifting. The way this gearbox prepares a gear train in advance is a distinctive feature of dual-clutch transmissions and is known as pre-shifting. The preparatory shifting on this system always has the next gear in the gear range for each clutch ready to be engaged. The preparatory shifting control is configured so that the gear range on the non-driven clutch side has readied the next gear up from the gear on the driven clutch side on which the vehicle is presently driving. The reason for this is that upward gear shifts, which mainly occur during acceleration, call for gears to be shifted in

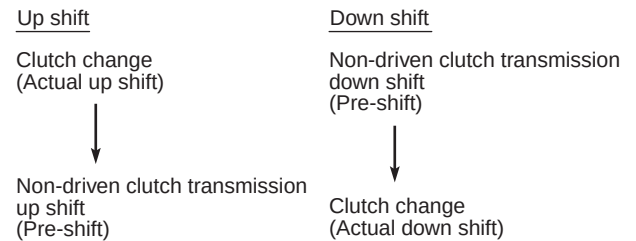


Fig. 4 Gearshift process

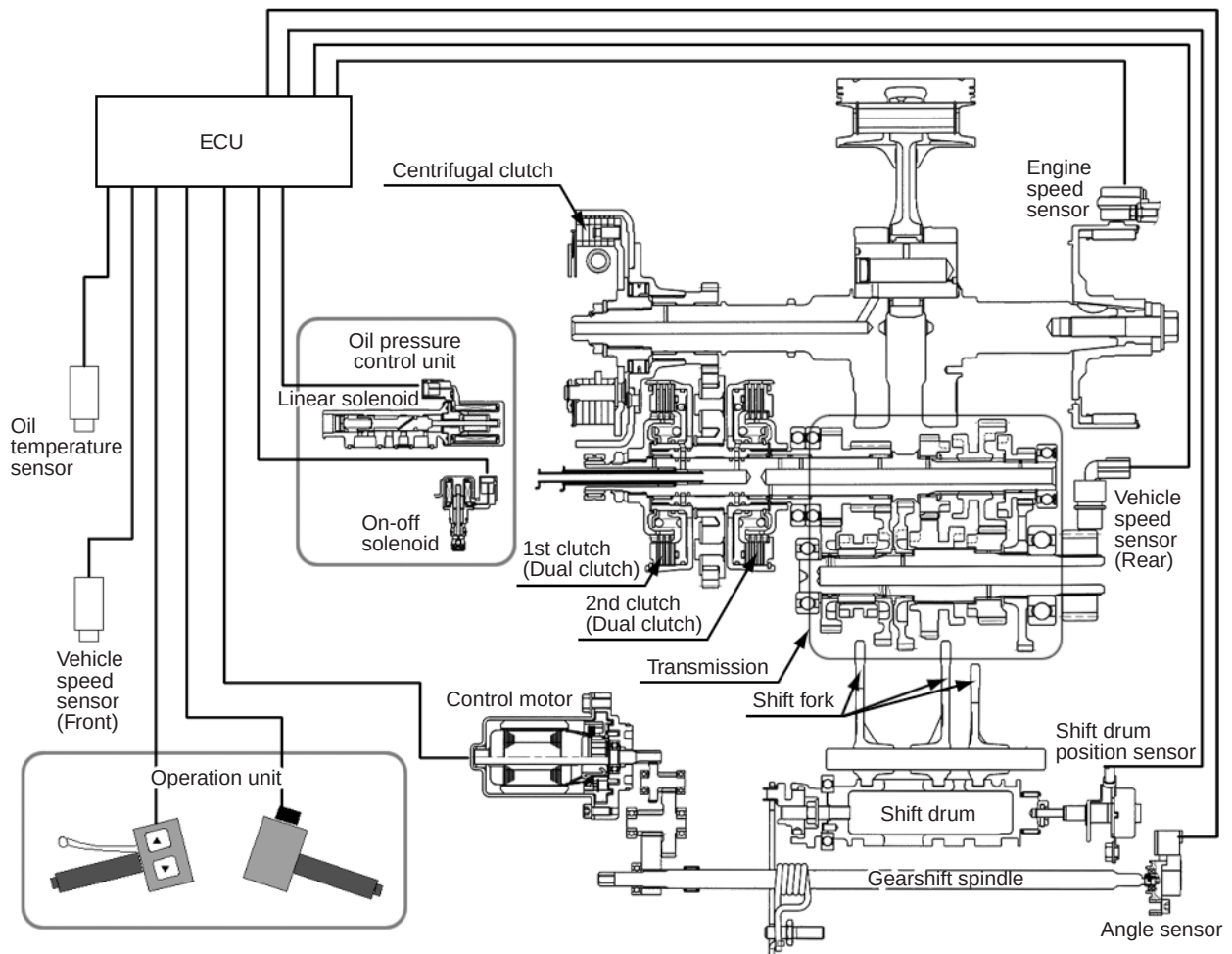


Fig. 3 System configuration

a short time so as not to lose the sensation of acceleration. Therefore, an upshift of gear can be accomplished simply by switching clutches. A downshift is performed by switching clutches after preparatory shifting takes place. Figure 4 shows the gear shifting process when upshifting and downshifting.

Switching between clutches is done by the on-off solenoid that switches hydraulic lines. The linear solenoid adjusts the hydraulic pressure during this process in order to reduce shift shock. Switching between gears in each gearbox is carried out by a motorized gearshift. The electronic control unit (ECU) computes the gear shifting by using the front wheel speed, rear wheel speed, throttle position, engine speed, and oil temperature. It checks these parameters against a transmission map and conducts the clutch switching control and preparatory shifting transmission control, accordingly.

4. Technical Features

4.1. Standing Start Control

Standing start control of vehicles with dual-clutch transmissions generally uses electronic hydraulic pressure control of the clutches to create a half-clutch state for a smoother start. Start control in the system developed here, however, uses the same mechanical control with a centrifugal-type clutch as used for ATVs with manual transmissions. This helps eliminate the need for an electronic control system and allows for a simpler system.

4.2. Construction of the Dual-clutch and Gear Train

Previous dual-clutch systems were known to have structurally complicated clutch units. The clutches used in this system are similar in construction to the single hydraulic clutch used in automobiles, and they are configured symmetrically on either side of the primary gear. Figure 5 shows the configuration of the transmission. Each clutch is connected by a clutch guide to the first and second main shafts, which are located on the same axis and supported in a double shaft structure so that they can rotate freely from each other. The gear engagement elements are of the dog type, generally used in motorcycles and ATVs with manual transmissions.

Adoption of this basic layout permits the dual-clutch attached to the primary gear to be placed in the location where a manual transmission vehicle has a multi-plate clutch attached to the primary gear. The construction of the first main shaft has added elements that are not found on the main shaft of a manual transmission vehicle, such as the clutch lubricating channel and the supports for the dual shaft unit. However, the shaft coordinates, shaft support method, gear coupling splines, and the shifter slide spline are among the elements they commonize. The countershaft differs in the placement of the gear train, but otherwise it is a commonized element.

4.3. Shift Shock Reduction Method

The method used to reduce shift shock is basically the same method using in general passenger automobiles. A linear solenoid is used to adjust the hydraulic pressure of the connecting side clutch to balance the driving force of the engine to the clutch capacity. This reduces the change in vehicle behavior resulting from sudden engagement of the clutch. A spool valve is used to gradually bleed off the hydraulic pressure of the disconnecting side clutch. Meanwhile, ATVs are fitted with low-pressure tires in order to drive off-road, and these tires also constitute a contribution to shift shock reduction. This has enabled reductions in the hydraulic circuit to be implemented, such as in the accumulation valve used to control the pressure regulating accuracy in ordinary passenger automobiles. The hydraulic circuit is shown in Fig. 6.

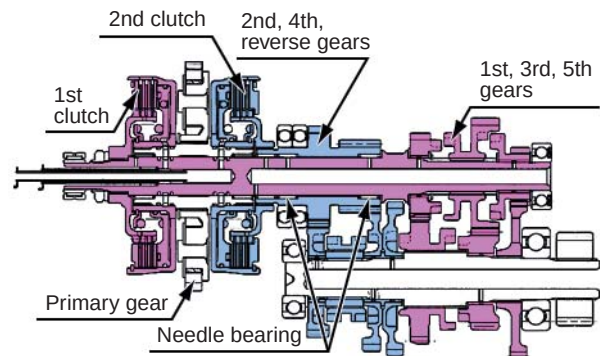


Fig. 5 Design of gears and clutches in transmission

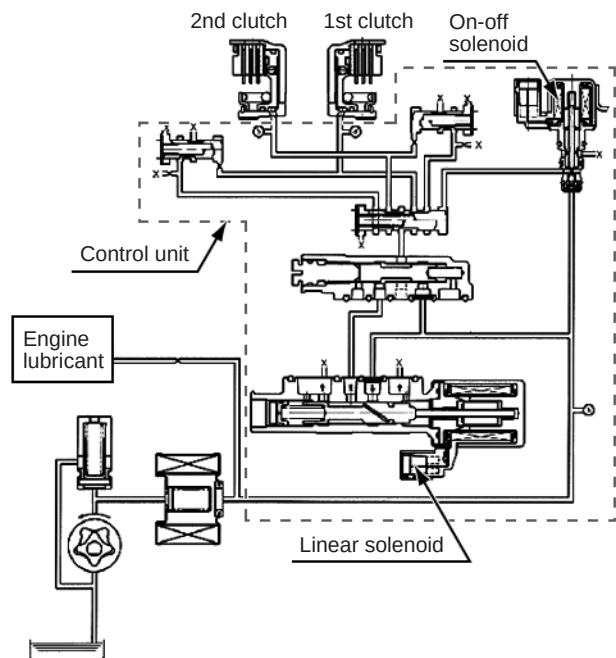


Fig. 6 Hydraulic circuit

The hydraulic control applied using the linear solenoid is divided into three phases. In phases 1 and 2, the system is rapidly placed in a half-clutch state. In phase 3, engine speed and throttle position are used to control the torque capacity of the hydraulic clutch. Figure 7 shows the control chart for the linear solenoid. At the same time that hydraulic control is applied, the engine ignition timing is also retarded slightly. This suppresses engine output so as to hold down the fluctuation in transmission torque when gear shifting takes place. This hydraulic control and ignition timing adjustment provide smooth gear shifting, and yield a shock during gear shifting that is on a par with vehicles that have an automatic transmission with a torque converter.

The valve body unit that performs hydraulic control was designed to hold the linear solenoid, on-off solenoid, and spool valve within a single unit in order to reduce faulty operation due to foreign matter contamination during manufacturing. This unit is attached to the front cover. From the front cover it is connected to the clutch by a feed pipe that supplies lubricant to the main shaft and the clutch. The parts containing high-pressure hydraulic channels were limited to these parts in order to simplify maintenance by limiting the parts subject to foreign matter control. The valve body units were designed to be assembled in a clean room exclusively for that purpose at the manufacturing plant, after which they

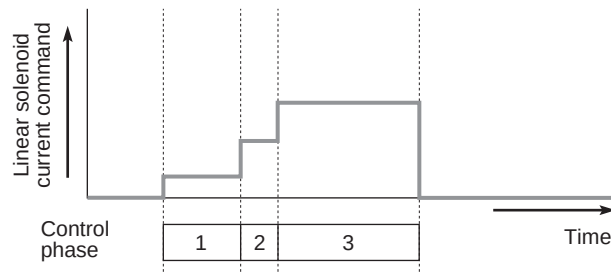


Fig. 7 Linear solenoid control chart

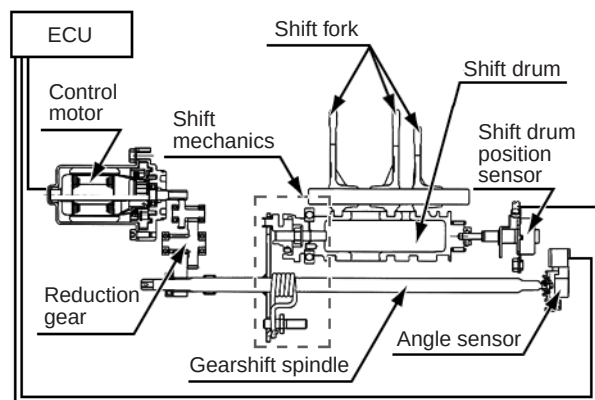


Fig. 8 Transmission system

are installed on the front cover. They are intended to be subject to verification of functionality and quality assurance.

4.4. Preparatory Shifting System and Its Method of Operation

The pre-shift on dual-clutch transmissions for conventional passenger automobiles have from three to four shift forks. These are all controlled in each. Therefore, as many operating devices, position sensors, and failsafe devices to reduce errors in joint operation were needed as there were shift forks. Motorcycles and ATVs, on the other hand, generally utilize sequential drum systems. Therefore, it was decided that the present system would also utilize the sequential drum method. The construction, operating devices, and control systems were accordingly carried over, without alteration, from the TRX420 motorized gearshift system. The transmission system is shown in Fig. 8.

Motorized gearshifts use a control motor to operate a manual transmission. The motor turns a change spindle, which makes the gearbox operate. The spindle position is detected by an angle sensor, while a shift drum position sensor determines when the travel is complete and the motor returns the spindle to a neutral position. A single motor operates the drum and moves three shift forks.

The drum is of the same construction as in an ATV with manual transmission. It differs, however, in that it is configured so that one position engages the respective gear trains of the first clutch and the second clutch. Moreover, the gear ranges in those respective gear trains are arranged so that the gears to be engaged are always adjacent. Table 2 shows the combinations of drum positions and engaged gears.

The preparatory shifting on the non-driven clutch side therefore changes two gear speeds ahead, and the relative difference in rotation when the dogs are engaged will be two gear speeds. This is why the dogs together generate undue noise. In order to reduce this noise when preparatory shifting occurs, a control function was added to bring it to a stop, once at a half-neutral position after disengaging from the previous gear, and before the next gear is engaged. Figure 9 shows the control of the control motor. The travel control applied by the control motor is divided into four phases. Phase 1 travels to a position halfway from the previous position to the next position.

Table 2 Shift drum position and engaged gears

Shift drum position (Sequential)		Reverse	Neutral	1-2	2-3	3-4	4-5	5
Engaged gear	1st clutch	—	—	1st	3rd	3rd	5th	5th
	2nd clutch	Reverse	—	2nd	2nd	4th	4th	—

Phase 2 holds at that position for a certain time. Phase 3 travels to the next position. Phase 4 returns the transmission to the original position. By means of this control, the speed on the non-driven side of the transmission is synchronized with the speed on the driven side without the addition of synchronizers or other such mechanisms. The relative difference in speed can be reduced to one gear speed before the next dog is engage. This reduces the impact energy of the dog engagement and limits the amount of rattling noise. Figure 10 shows the rotation difference when preparatory shifting takes place. This gear shifting operation only adds the control described above, stopping at half-neutral, to the previous motorized gearshift. The previous system was therefore able to be carried over, for the most part, without any change. This system was also made simpler than the preparatory shifting system in automobiles.

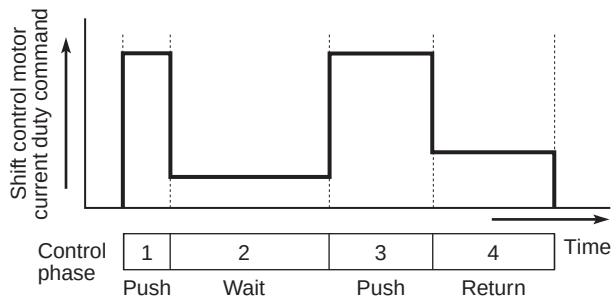


Fig. 9 Control of control motor

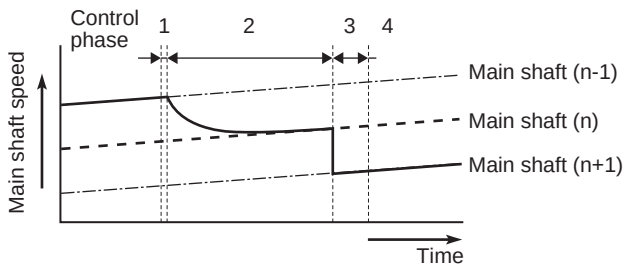


Fig. 10 Rotation difference

5. Shift Control Mode and Its Method of Operation

Selection of the gearshift mode and traveling range are by-wire operations. They are conducted using the upshift and downshift switches on the left handlebar and the gearshift mode switch installed on the right handlebar. The arrangement of the switches is shown in Fig. 11. The gearshift mode switch can be switched between “AUTO” for automatic gearshift mode, and “ESP” to select any gear range desired by the rider. In AUTO mode, the upshift switch can be pressed to choose to shift to R (reverse), N (neutral), or D (drive), in that order. The

downshift switch does the opposite, switching the selection from D to N to R in that order. When shifting from N to R, an interlock needs to be released at the same time, in the same way as in current models. In ESP mode, the upshift switch shifts up and the downshift switch shifts down. The rider can therefore freely select the desired gear range.

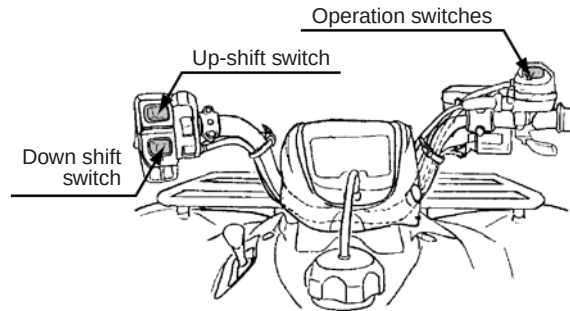


Fig. 11 Arrangement of switches

6. Conclusion

A dual-clutch transmission system was developed with the goal of providing running-through performance suitable for an ATV while also providing both an easy ride and an enhancement in fuel economy relative to previous ATV automatic transmissions, including the hydraulic-mechanical transmission.

- (1) The transmission shaft arrangement and the locations at which the clutch and change gear are attached were made the same as on a vehicle with manual transmission. The frame was also shared with the manual transmission vehicle.
- (2) Making use of distinctive ATV characteristics, the hydraulic control circuits were simplified and the motorized gearshift was carried over to the new system for use in preparatory shifting. These steps realized a system that is simpler, lighter in weight, and more compact than the previous systems in automobiles.
- (3) Shift shock was reduced to the level of an automatic transmission with a torque converter by using electronic control of the hydraulic pressure through a linear solenoid and by making use of distinctive ATV characteristics.
- (4) Preparatory shifting was accomplished without using a synchronizer or other such special mechanism. The use of motor control can reduce relative rotation speed as well as undue mechanical noise.

References

- (1) Ota, A., Narita, S.: Utilization of Motor-Driven Gearshift System, SAE Paper, 1999-01-0745 (1999)
- (2) Hori, Y., Hamaoka, S., Tawara, H., Nakazawa, T.: Development of an Engine with 3-speed Automatic

Transmission for “TRX650FA,” Honda R&D Technical Review, Vol. 15, No. 1, p. 69-76 (2003)

- (3) Saitoh, M.: Development of ATV Electronic Controlled HMT system, Hydraulic & Pneumatics, Vol. 40, No. 3, p. 16-19 (2001)
- (4) Yamamori, T., Shibayama, N., Amamiya, I.: Automatic Transmission for Automobile, Sankaido Publishing, 229p. (2005)

■ Author ■



Kinya MIZUNO



Seiji HAMAOKA



Eiji KITTAKE



Masaki KOBAYASHI