

Development of New Honda 6-speed Automatic Transmission for MDX

Isamu SHINBORI*

Akio MUTO*

Hiroyuki TAKEO*

Tooru TAKAHASHI*

Yoshiharu SAITO*

Yoshimichi TSUBATA*

ABSTRACT

A new Honda 6-speed automatic transmission (AT) for the MDX has been developed with the aims of enhancing fuel economy, raising efficiency, and achieving greater compactness. The unit was built on a parallel-shaft structure similar to the previous Honda AT, which has high torque transmission efficiency. The new AT incorporated an additional gear stage and the ability to handle higher input torque from the engine. Meanwhile, providing for a common gear train and placement of the forward-reverse shift mechanism on the input shaft were performed. As a result of these and other measures, the overall length of the new transmission becomes 18 mm shorter than the 2007 model 5-speed AT for the MDX. A multi-plate lock-up clutch (LC) structure with a separate chamber in the torque converter was also adopted so that LC capacity could be increased and the LC control area expanded. In combination with the new hydraulic control system, this new configuration achieves a 5% or greater increase in fuel economy over that of the 2007 model year MDX while realizing greater power and driving performance with enhanced direct feeling.

1. Introduction

Global warming due to increasing levels of greenhouse gases is a shared global issue, and responses are demanded from all sectors of industry. There are growing demands on the automotive industry to increase fuel efficiency in order to reduce CO₂ emissions, and urgent responses are necessary. In addition, the achievement of increased commercial appeal and enhanced drive feel is also demanded.

In the area of automotive transmissions, Honda has worked to increase fuel efficiency through measures including employing CVT⁽¹⁾, ⁽²⁾ and IMA⁽³⁾, and expanding the LC control range, primarily in small and medium-sized vehicles. A 6-speed AT has now been developed as a new structure with the aim of increasing fuel efficiency in large vehicles.

The total length of the new 6-speed AT has been reduced, and at the same time, increased fuel efficiency as well as enhanced dynamic performance and drive feel have been achieved. This paper will discuss the aims for the development of the new 6-speed AT and the main technologies employed in the unit.

2. Development Goals

Controlling engine speed during vehicle operation to a low level reduces the amount of fuel consumed, and the use of an additional gear stage is therefore an effective method of increasing fuel efficiency. When shift clutches and shift gears are added to a conventional parallel-shaft transmission, the overall length of the transmission increases, and this can affect crash safety by reducing clearance with the body frame, and can reduce the flexibility of installation in car bodies. Given this, it is necessary to reconcile the increase in the number of gear stages with the reduction of the overall length of the transmission unit.

With regard to the torque capacity of the transmission, taking the higher torque of next-generation engines into consideration, it is necessary to design the transmission on the basis of an upper limit target torque for the structure.

In addition, while responding to demands for increased fuel efficiency, it is also necessary to enhance drive feel and increase commercial appeal.

Based on the above, the following three main aims

* Automobile R&D Center

were set for the development of the new 6-speed AT:

- (1) Reconcile increase in the number of gear stages with reduction in overall length
- (2) Realize high torque capacity for next-generation engines
- (3) Reconcile increased fuel efficiency and enhanced drive feel

3. Basic Structure and Main Specifications

Figure 1 shows the main section of the new 6-speed AT. The main specifications of the transmission are listed in Table 1. Figures 2 and 3 show a vehicle speed map and the transmission appearance, respectively.

The new AT uses the parallel-shaft structure of a conventional Honda AT, which displays a good friction characteristic. The following innovations have been applied:

- (1) The 2nd, 3rd, and reverse gear trains are shared.
- (2) The 4th, 5th, and 6th gear trains are shared.
- (3) The forward-reverse shift mechanism, previously positioned on the counter shaft, has been positioned on the third shaft.
- (4) Bolt tightening structure rather than nut tightening is used for the counter shaft and secondary shaft tightening.
- (5) A new form of engine brake control has been employed, enabling the low-hold clutch to be eliminated.

These five innovations have enabled the use of an additional gear stage while reducing its overall length by 18 mm.

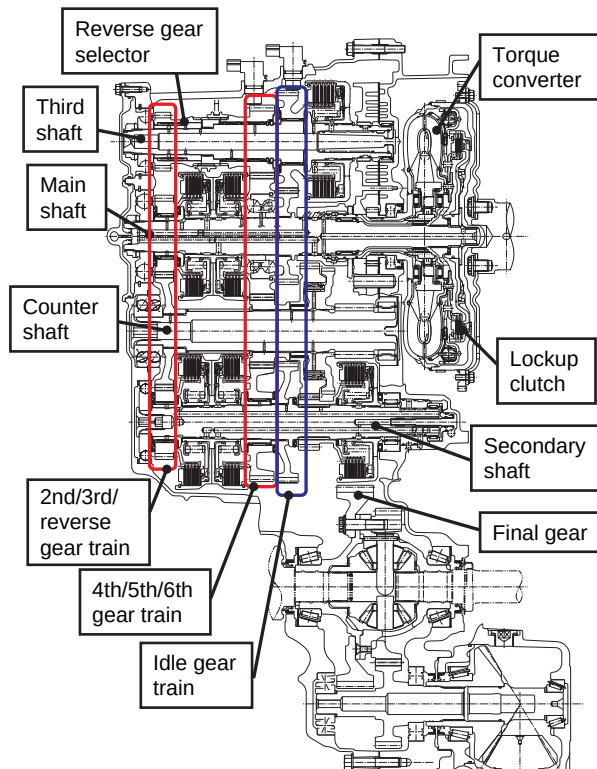


Fig. 1 Main section of Honda 6AT

Table 1 Specifications of 6AT

Transmission type		6-speed automatic
Torque capacity [Nm]		400
Ratios	1st	3.359
	2nd	2.094
	3rd	1.484
	4th	1.065
	5th	0.754
	6th	0.555
	Reverse	2.269
	Idle	1.282
Ratio range		6.05
Overall length [mm]		375

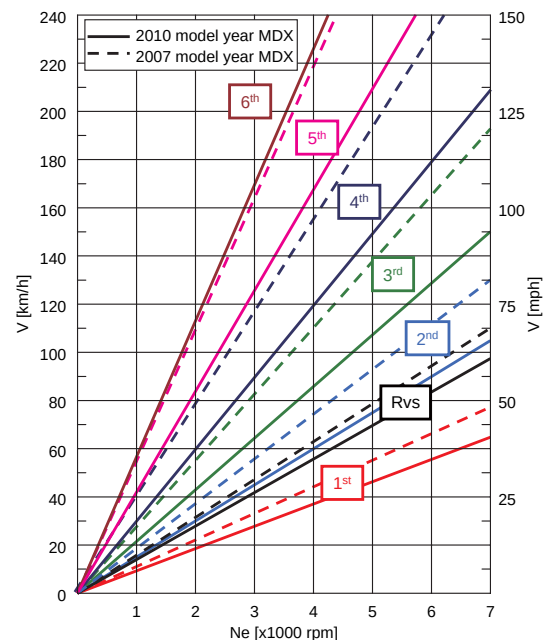


Fig. 2 Vehicle speed map

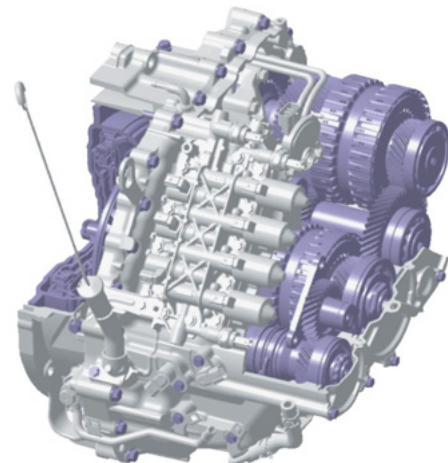


Fig. 3 Appearance of Honda 6AT

With the use of an additional gear stage, it becomes possible to employ wide-range gear ratios, and lower gear ratios at low gear stage. The ratio of 1st gear is 17% lower, and the ratio of the top gear (6th gear) is 3% higher than those of the 2007 model year MDX. These gear ratio settings enabled increased fuel economy to be reconciled with enhanced drive feel.

The use of a thin, wet-type multi-plate clutch with large-diameter⁽⁴⁾ for the LC enabled the LC capacity to be increased and the LC control range to be expanded⁽⁵⁾, helping to realize increased torque capacity and increased fuel economy.

4. Main Technologies

4.1. Study of Strength of Gears, Shafts, and Cases

Using CATIA V5, a stiffness analysis of a full 3D model of the transmission was conducted, enabling high-accuracy prediction of gear and shaft inclinations and the load on the bearings⁽⁶⁾. This analysis enabled the case specifications and multi-shaft gear mechanism to be optimized, resulting in a reduction in overall length and enhanced gear meshing.

All the torque transmission and support parts, including the gears, shafts, and cases, were 3D modeled, and an analysis of stiffness under conditions of maximum engine torque input was conducted with consideration of the clearance of each part and other factors. The analysis model is shown in Fig. 4. The model took gear inclinations, shaft deflections, and other factors into consideration. Because the stress analysis of the cases could be conducted under conditions approximating those in an operating transmission, prediction accuracy was increased, and it was possible to front-load development. Figure 5 shows the results of the stress analysis of the cases.

The pressure distribution on the surfaces of the gear teeth and the cumulative stress on the gear roots were

determined with consideration of the gear and shaft inclinations obtained from the abovementioned analysis⁽⁶⁾. With a strength map of the gear materials obtained using a unit gear tester as a reference, the strength of the gears for each speed and the final gear was examined, and durability predictions were made for the gears. At the same time, the same method was used with the teeth in contact during input of cruise torque, enabling prediction of the effect on gear noise. Figure 6 shows the distribution of pressure on the surface of the final gear. Figure 6(a) shows the cumulative pressure distribution for all gear speeds when full torque is transmitted, prior to correction of the shape of the gear teeth. The pressure is concentrated at the irregular sections of the gear teeth, and the peak pressure is high. Figure 6(b) shows the cumulative pressure distribution for all gear speeds following correction of the shape of the teeth based on the results of the analysis discussed above. The results show that the corrected tooth shape prevents localized concentration of pressure by dispersing pressure across the entire width of the tooth, and reduces peak pressure, thus increasing durability. Figure 6(c) shows the pressure distribution for the corrected tooth shape when 6th gear cruise torque is being transmitted. The results show that while the tooth shape takes durability into consideration, at the same time a good area of contact is obtained in meshing in the standard-use range. Figure 7 shows the results of NV measurements for the final gear. NV measurements of the tooth shape for which noise

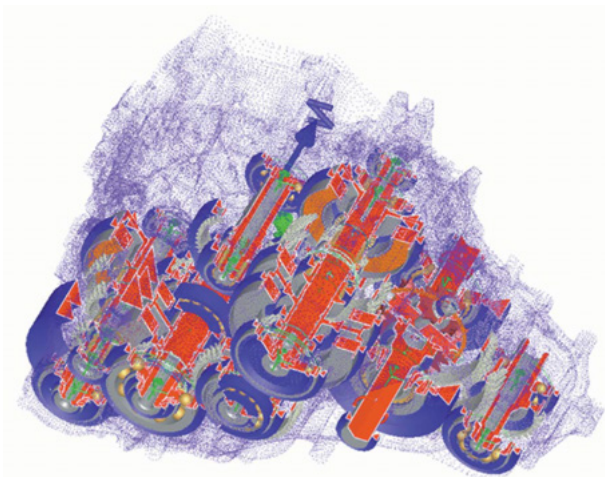


Fig. 4 Analysis model

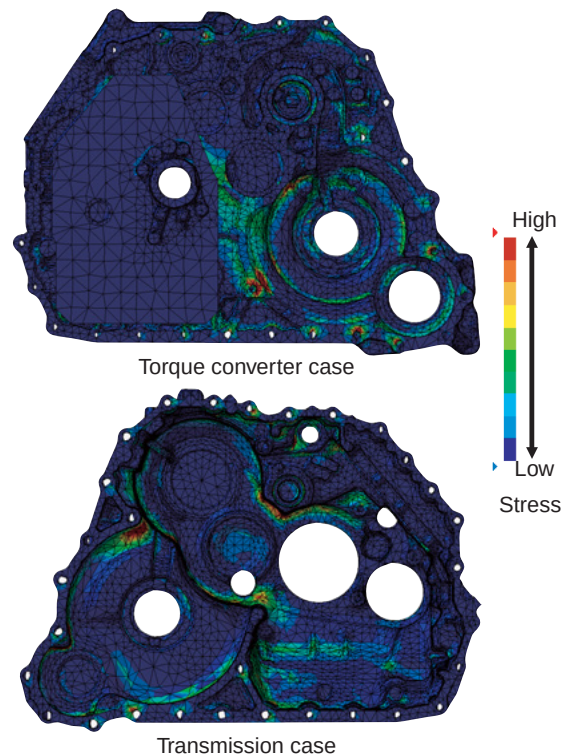


Fig. 5 Stress analysis result for cases

predictions were made for tooth contact during transmission of full torque and cruise torque show that the tooth shape satisfies the targets set for it.

4.2. Multi-plate Lock-up Clutch

A multi-plate lock-up clutch (LC) in a separate housing was employed to enable response to high-torque engine input. Figure 8 shows the oil flow when the torque

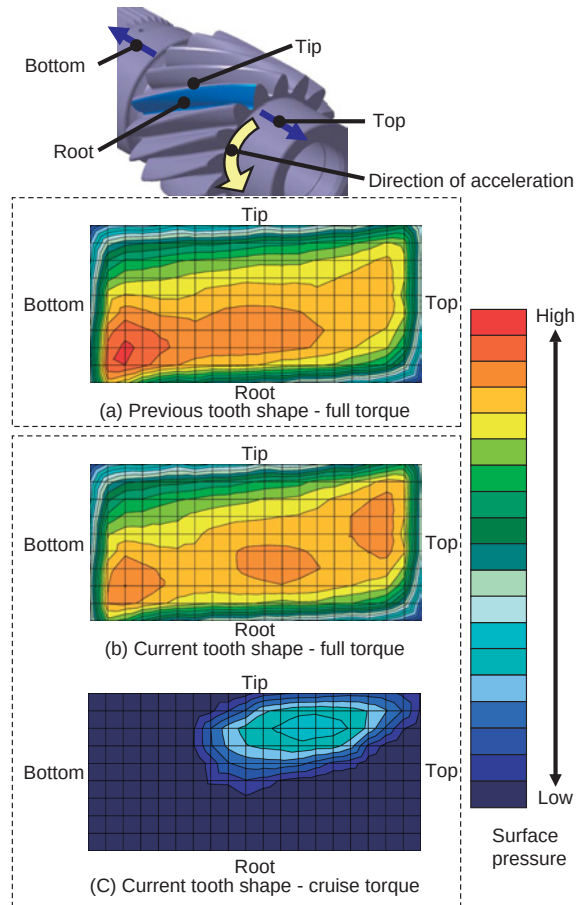


Fig. 6 Pressure map of final gear

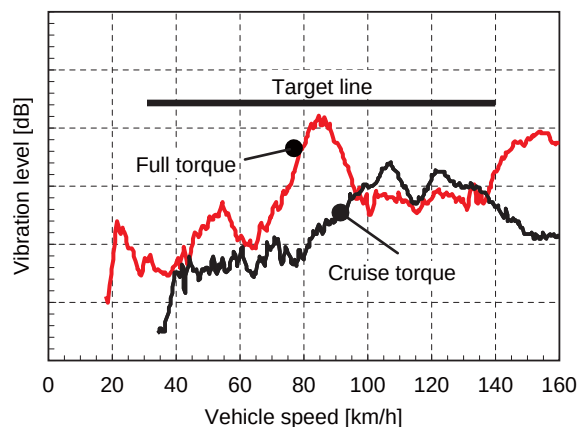
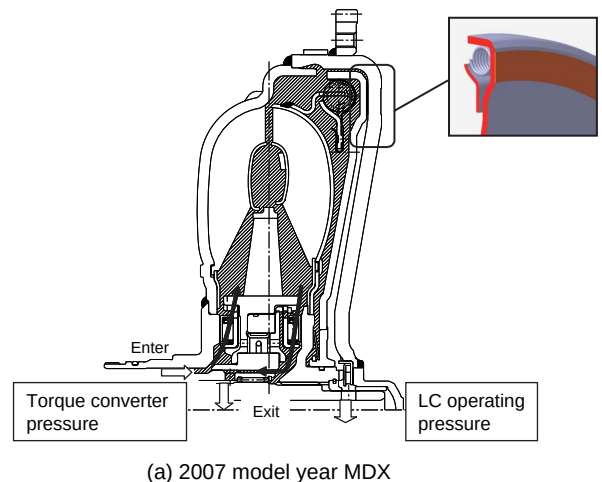


Fig. 7 Final gear NV

converters used in the AT in the 2007 model year MDX and in the developed 6-speed AT are engaged⁽⁵⁾. In order to increase the range for engagement against the former single-plate LC clutch, a wet-type multi-plate clutch with the same structure as the shift clutches has been employed. To help ensure space with the use of a multi-plate clutch, the flatness rate of the torque converter was reduced to 51% from the 65% of the unit used in the 2007 model year MDX. While LC control could be applied simply by adjusting the internal pressure of the torque converter for the single-plate LC, in the case of the multi-plate LC, the LC capacity is controlled by maintaining the internal pressure of the torque converter constant and adjusting the back pressure of the pistons, as in the shift clutches.

In the previous single-plate LC, the LC facings could not be cooled by the oil flow in the torque converter when the LC was engaged. The use of a new LC control method and an LC facing provided with lubrication grooves in the new multi-plate LC has enabled the LC discs to be cooled by the oil flowing in the torque converter, enhancing LC



(a) 2007 model year MDX

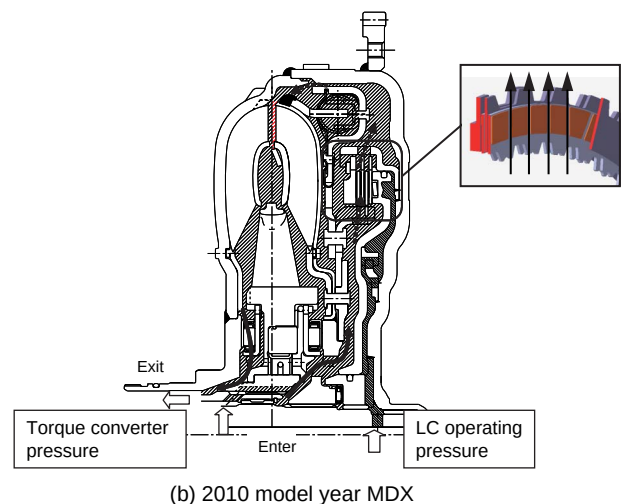


Fig. 8 Structure of torque converter

cooling performance and increasing allowable heat generation. This has enabled the LC to be engaged under transient operating conditions, such as wide-open throttle. Figure 9 shows the LC control range⁽⁵⁾. The expansion of the LC control range to the high throttle opening and low engine speed ranges has helped to increase fuel efficiency and realize a drive feel with a powerful directness.

4.3. Low-friction Hydraulic Circuit

A new hydraulic control circuit was employed in order to increase fuel efficiency and reliability. Figure 10 shows the hydraulic control circuit used in the new 6-speed AT.

In the 2007 model year MDX, the line pressure was maintained constant, while ON/OFF control was applied to the lubrication pressure in D range, and lubrication cut-off control was applied in the P, R, and N ranges. In the new 6-speed AT, two-stage Hi/Lo switching control is applied to the line pressure, reducing the load on the oil

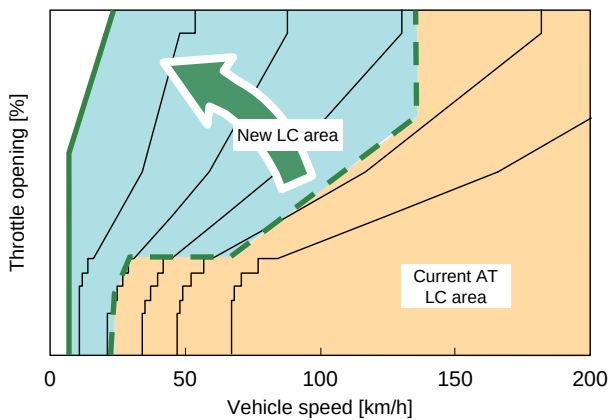


Fig. 9 Lock-up clutch map

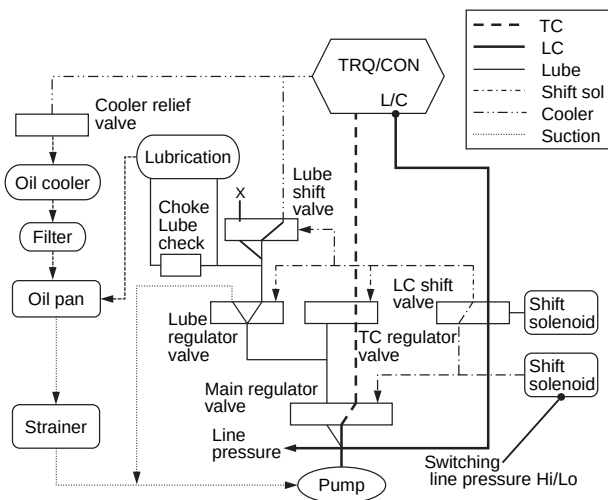


Fig. 10 Hydraulic circuit

pump; lubrication pressure is adjusted in order to help ensure stable supply of lubricating oil; lubrication control is applied in the P, R, and N ranges; and the amount of lubrication at low temperatures is limited by the choke. These measures have helped to ensure the durability of the mechanical parts under high loads, and have reconciled this with the achievement of increased fuel efficiency through the reduction of the load on the oil pump at low loads and the reduction of clutch friction by the lubricating oil.

4.4. Modularized Valve Body

The electrical devices in the 6-speed AT were modularized in order to reduce size, increase quality and performance, and realize greater ease of maintenance. Figure 11 shows the modularized valve body (secondary valve body). Bodies formed from linear solenoids and shift solenoids are in a back-to-back structure with the valve body, which includes accumulator pistons.

In the 2007 model year MDX, clutch pressure was adjusted by means of the linear solenoid units. The modular configuration employed in the new 6-speed AT enables adjustment of pressure and maintenance of hydraulic pressure with the constituent parts of the hydraulic circuit such as the shift valves and the accumulator pistons incorporated, and this enables clutch pressure to be maintained with a higher degree of accuracy. Figure 12 shows the method of linear solenoid pressure regulation used in the modular configuration. With the starting pressure supplied by the line pressure hydraulic channel of the secondary valve body and a prescribed current impressed in the linear solenoid, the adjust cap is pressurized until the prescribed value for pressure in the output hydraulic channel is reached, and the load on the spring set is adjusted. This method of pressure regulation has increased the accuracy of clutch pressure, and has reduced shift shock.

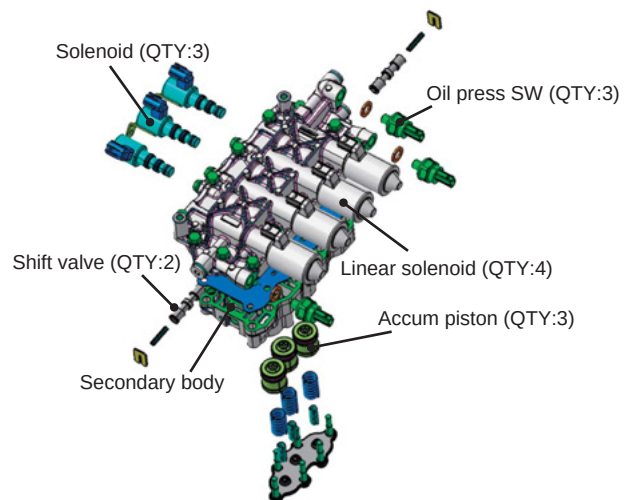


Fig. 11 Secondary valve body assembly

4.5. Lubrication Oil Management

In order to increase cooling efficiency by reducing friction and controlling aeration and to enable the use of oil splashes to lubricate the surfaces of the gear teeth, a plastic baffle plate molded in one piece is installed in the transmission case. Figure 13 shows the baffle plate, and Fig. 14 shows the mounting of the baffle plate and the flow of lubricating oil.

The baffle plate is positioned so as to cover the underside of the main shaft, and the ribs of the case are set around the differential. This has divided the interior of the case into three compartments, for mechanical components, the differential, and the strainer. This arrangement prevents the lubricating oil that is supplied from the shaft to the clutches, gears, and bearings from directly striking the oil around the strainer, thus controlling aeration of the oil. In addition, the form of the baffle plate follows the arrangement of the gears for each speed, enabling lubrication of the surfaces of the gear teeth by the oil flowing on the baffle plate. This has contributed to the achievement of increased durability in the gears.

The baffle plate has been provided with oil supply holes, and the supply of lubricating oil to the differential and the recirculation of lubricating oil to the area around the strainer inlet have optimized the oil level while driving and reduced agitation resistance due to the gears.

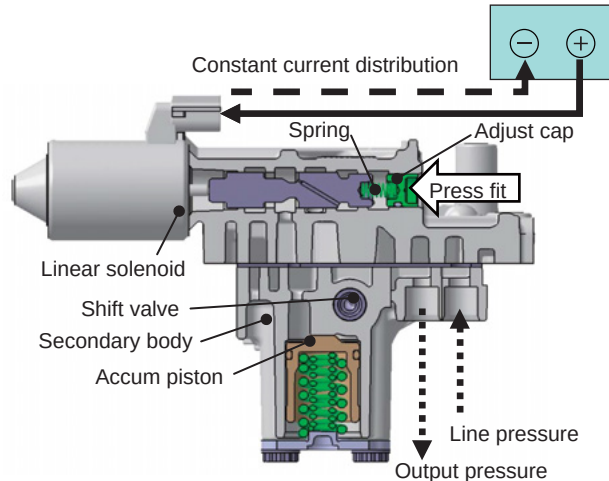


Fig. 12 Linear solenoid pressure regulation method

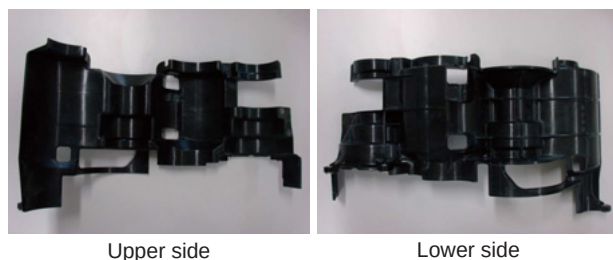


Fig. 13 Baffle plate

4.6. New Engine Brake Control

When the engine brake is applied in an AT vehicle, the shift lever is operated, and the position is shifted to the L range, setting 1st gear as the drive gear. When 1st gear is set as the drive gear in an AT with a one-way clutch below 1st gear, the one-way clutch idles during deceleration, making it necessary to engage a low-hold clutch in order to set 1st gear as the drive gear.

The low-hold clutch has been done away with in the new 6-speed AT by means of the gear ratio settings, shifting during application of the engine brake, and LC control. Figure 15 shows the details of the new engine brake control, and Fig. 16 shows a comparison of deceleration torque with the 2007 model year MDX.

In the new engine brake control system, the vehicle

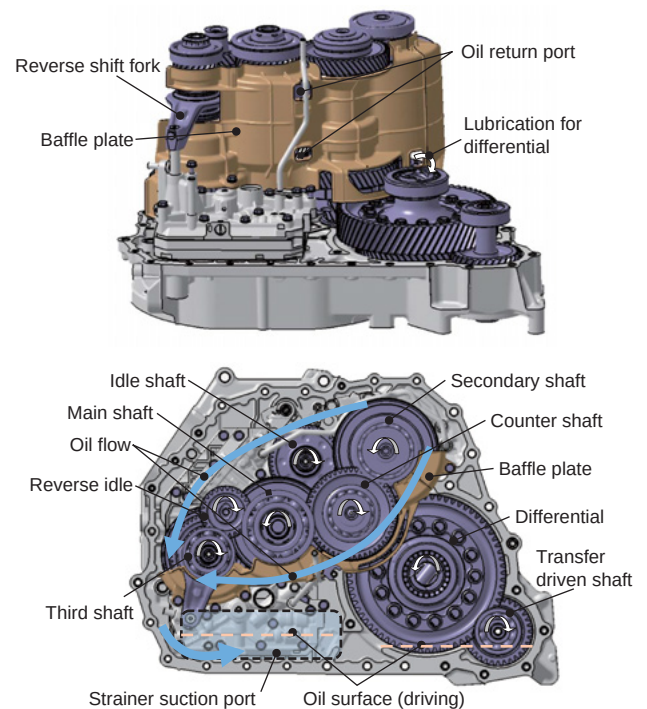


Fig. 14 Assembled baffle plate

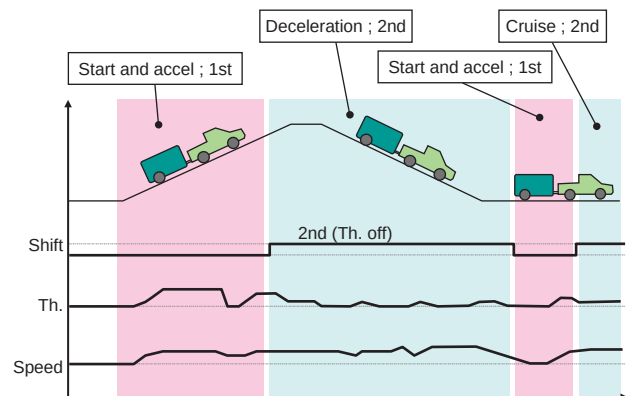


Fig. 15 New engine brake control

is operated in 1st gear when driving at low speed in the L range, and at high speed when the gear shifts to 2nd gear. The system kicks down from 2nd gear to 1st gear when acceleration torque is necessary. When the engine brake is necessary, such as when descending a slope or when the accelerator pedal is fully closed, 2nd gear is set as the drive gear, preventing idling of the one-way clutch. In order to help ensure torque during deceleration, the ratio of 2nd gear has been set 22% lower than the ratio used in the 2007 model year MDX. In addition, the use of a multi-plate LC has enabled the LC to be engaged during deceleration, increasing torque during deceleration by 7% compared to the level when the LC is not engaged. The use of a low ratio for 2nd gear and the engagement of the LC have enabled the realization of an optimum deceleration torque setting in 2nd gear drive, even without the use of the low-hold clutch. The previous use of L range when descending a hill necessitated frequent operation of the accelerator and manual switching between 1st and 2nd gears in order to maintain a high vehicle speed. In the new 6-speed AT, the ratio of 2nd gear is set for linear deceleration torque in relation to the vehicle speed, making frequent accelerator operation and manual switching unnecessary, thus increasing drivability.

4.7. Protection Control

The range of operation of protective control (hardware protection) against user misuse has been increased in comparison to a conventional AT vehicle. The new control achieves the same or higher level of performance compared to that of a conventional AT vehicle. The control encompasses torque limitation, vehicle speed limitation, and shift limitation in order to protect the forward-reverse switching mechanism when the vehicle is put in gear at a high engine speed, forward operation is engaged when the vehicle is in reverse, and the forward-reverse switching mechanism is operated when the vehicle is on ice. In addition, stall torque is limited in order to help prevent an increase in the ATF temperature when the vehicle is continuously stalling.

Table 2 shows an overview of the forms of control

Table 2 New control of mode protection targets

Mode protection target	Protection items	Control	Control target
In-P on ice by mistake	Parking	Speed limit	FI coordination (F/C)
Normal drive	Clutch	Shift limit	AT (shift)
	LC	Slip ratio limit	AT (LC)

newly applied in the developed 6-speed AT for the various control targets. Projecting a situation in which the P range is accidentally engaged when the driver is attempting to get off a snowdrift by switching between forward and reverse and the drive wheels are spinning on the snow, the speed of rotation of the drive wheels is limited in order to protect the parking gear and the parking brake pawl. In addition, a new form of control has been employed in order to control heat generation by the LC and the shift clutches. An ECU predicts the level of heat that will be generated by each clutch, and judges whether or not protective control should be applied. The target value for heat generation is set relatively higher for driving on flat roads, and for the transient use range of the slip control under high throttle opening conditions at low engine speeds or immediately before a kick down, as long as normal LC control is applied. However, when the level of heat generated remains continuously at the target value for a specified period or longer, the target value is changed to the target value for the other operating ranges. If a high level of heat continues to be generated despite this, the LC is disengaged. In addition, for protection of the shift clutches, shift delay control and other forms of control have been employed in order to prevent the temperature of the clutch plates from increasing. These protective control measures were tested in an actual vehicle, and were found not to result in excessive intervention of control, and to have no effect on the normal usability of the vehicle.

5. Fuel Economy and Driving Performance

5.1. Friction and Transmission Efficiency

The use of two-stage Hi/Lo switching control for line pressure in response to the torque that must be transmitted by each clutch and the reduction of oil agitation resistance by means of the use of a plastic baffle plate molded in one piece and modification of the shape of the case have reduced friction torque by 20% at 100 km/h against the 2007 model year MDX. Figure 17 shows measurements of friction torque.

In addition to this reduction of friction torque, the optimization of gear tooth contact with consideration of gear inclinations has increased transmission efficiency during cruising by 0.7%. Figure 18 shows measurements of transmission efficiency during cruising.

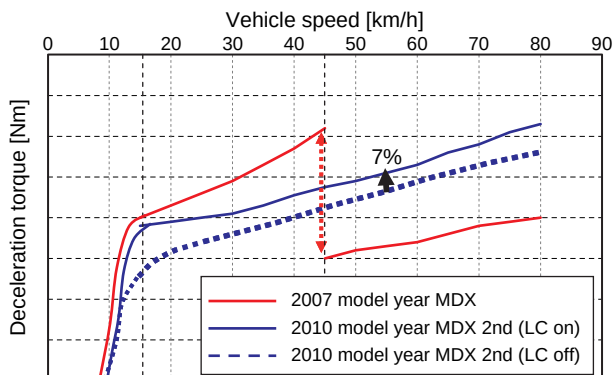


Fig. 16 Deceleration torque

5.2. Fuel Economy

The use of an additional gear stage, the expansion of the LC control range through the use of a multi-plate LC, the reduction of friction torque, and the realization of increased torque transmission efficiency have increased fuel efficiency by more than 5% against the 2007 model year MDX. Figure 19 shows the rate of increase in fuel efficiency against the 2007 model year MDX in each testing mode. Figure 20 shows a breakdown of the different factors in the realization of increased fuel efficiency in U.S. combined mode.

Figure 19(a) and (b) shows the rate of increase of fuel efficiency in the current testing modes and in the new testing modes scheduled for use from 2012, respectively. The new model displays increased fuel efficiency by more than 5% in both the current and new modes. The measurement conditions used in the new modes are particularly close to actual use conditions, and these results therefore suggest that fuel efficiency in actual use has also increased.

A number of factors that have contributed to this

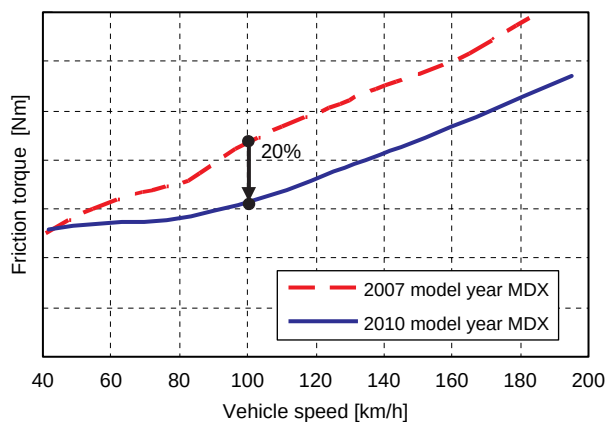


Fig. 17 Friction torque

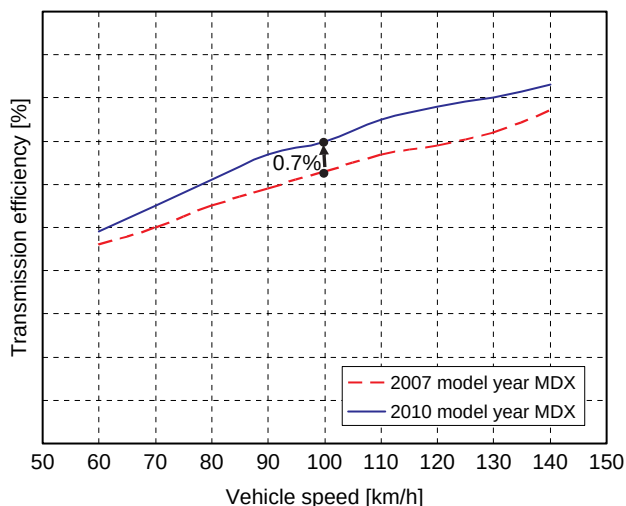


Fig. 18 Transmission efficiency

increased fuel efficiency can be enumerated, including the achievement of increased torque transmission efficiency, the expansion of the LC control range, and the use of an additional gear stage. The achievement of increased torque transmission efficiency has contributed to increased fuel efficiency in all modes. The contribution of the expansion of the LC control range was small in HWY mode, which features little acceleration and deceleration. However, the expansion of the LC control range was confirmed to contribute to increased fuel efficiency in other modes, during acceleration and deceleration and under low-temperature operation. The use of an additional gear stage also had an effect in increasing fuel efficiency by reducing the input engine speed and extending the period for which fuel is cut.

5.3. Driving Performance

Lower gear ratios at low gear stage and wider LC direct drive range have reduced the time for acceleration from 0-60 mph by 0.8 sec and the time for acceleration from 50-70 mph by 0.9 sec with a wide-open throttle against the 2007 model year MDX. In addition, wider LC direct drive range has resulted in the achievement of a drive feel with powerful directness, as obtained from a manual transmission vehicle.

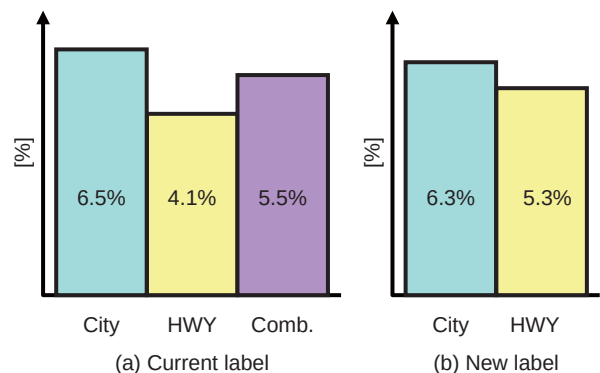


Fig. 19 Fuel economy enhancement

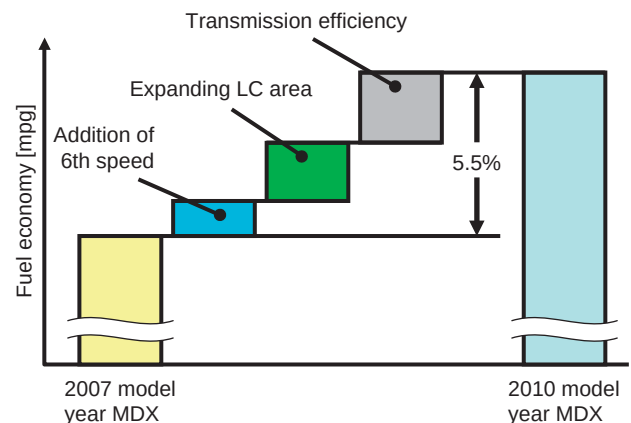


Fig. 20 Detail of fuel economy enhancement

6. Conclusion

A new 6-speed AT was developed in order to increase fuel economy, achieve increased efficiency, and realize greater compactness. The following results were obtained:

- (1) The use of shared gear trains, positioning the idle gear on a separate shaft, positioning the forward-reverse switching mechanism on the third shaft, the use of bolt tightening structure for the shaft, and the application of a new form of engine brake control have enabled the low-hold clutch to be done away with, enabling overall length to be reduced by 18 mm, despite the employment of an additional gear stage, and the realization of increased torque capacity.
- (2) The expansion of the LC control range through the use of a multi-plate LC, and the reduction of agitation resistance through the use of a new form of hydraulic control and lubrication oil management have increased fuel efficiency by more than 5%.
- (3) While fuel economy has been increased, a wider range of gear ratios, lower gear ratios at low gear stage, in addition to wider LC direct drive range, have enhanced driving performance and enabled the realization of a drive feel with a powerful directness.

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■ Author ■



Isamu SHINBORI



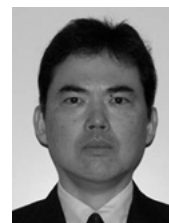
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Hiroyuki TAKEO



Tooru TAKAHASHI



Yoshiharu SAITO



Yoshimichi TSUBATA