

Development of Super Handling-All Wheel Drive System for SUV

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ABSTRACT

A rear differential unit suitable for SUV vehicles was developed based on the super handling – all wheel drive (SH-AWD) unit that was mass-produced for the LEGEND. This newly developed rear differential unit has a higher torque capacity and is smaller and lighter than the previous SH-AWD. Redefining the demanded performance of the rear differential unit, according to the characteristics of the vehicle in which it is to be used, resulted in a balance of increased maximum torque and weight reduction. To achieve the development goals, selection of the optimal ratio (speed-increasing ratio), a clutch capable of high μ with low abrasion, and an actuator that optimally control the new clutch were mentioned.

1. Introduction

The SH-AWD system, mass-produced for the LEGEND in 2004, enhanced cornering performance while reducing the burden on the driver by the four-wheel drive system.

Now, the SH-AWD system is also mounted in the RDX and MDX released in 2006, and these models use a newly developed rear differential unit.

This newly developed rear differential unit is based on the torque control structure by direct electromagnetic clutch which is the main feature of the SH-AWD system. The performance demanded from the 4WD system has been set with consideration of the applied vehicle's characteristics. Also, the maximum output torque has been increased and the weight and size have been reduced by using the optimum settings for each element.

This paper mainly presents an overview of the newly developed rear differential unit and its major technologies.

2. Development Goals

The goals for this new rear differential unit development were set as follows.

- Enhance cornering performance (relative to the previous vehicle) based on free control of the four-wheel drive force
- Simultaneous achievement of higher output, smaller size, and lighter weight

Development was conducted with a focus on the following items as technical elements for realizing the above goals:

- (1) Speed-increasing ratio settings that match the vehicle's characteristics
- (2) A new clutch achieving both the high μ and low abrasion
- (3) Actuator settings suited to the new clutch

3. Basic Structure and Specifications

Figure 1 shows the unit appearance, Fig. 2 shows the main cross-section view.

The overall structure closely resembles the VTM-4 (Variable Torque Management® 4-Wheel Drive System) shown in Fig. 3, which was mounted in the first-generation of the MDX, PILOT, and RIDGELINE, but the double-reduction configuration using a hypoid gear and

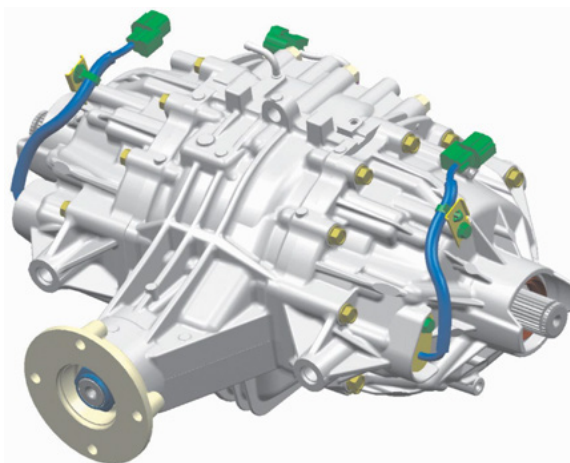


Fig. 1 View of newly developed rear differential unit

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planetary gear is based on the SH-AWD.

A hypoid gear, set to a dedicated ratio, and a lubricating pump are located in the center section. The case configuration has a back and front two-block construction similar to that of the VTM-4, and the case is also produced by the same high-pressure die-cast manufacturing method.

The difference in the center section from the VTM-4 is that the hypoid ring gear mount has been changed from a ball bearing to a tapered roller bearing. This was done to increase the gear mounting stiffness and to reduce weight by reducing the bearing size.

Figures 4 and 6 show the developed rear differential unit structure, and Fig. 5 shows the VTM-4 structure.

A bearing set plate and M8 flange bolt, that secures this plate to the case, have been added for the developed rear differential unit.

An axial load (called a preload) is needed to make the tapered roller bearing function properly. However, when using a front and back divided case, a device (jig) that

compresses the bearing is needed during assembly. Therefore, the bearing set plate structure makes it possible to apply a preload after case coupling. Therefore, mounting stiffness can be increased while ensuring ease of assembly.

The right and left clutch control sections have a configuration similar to that of the previous SH-AWD. (Fig. 7) The control sections are comprised of the following three elements:

- (1) Planetary gear assembly
- (2) Multiplate wet clutch
- (3) Electromagnetic solenoid

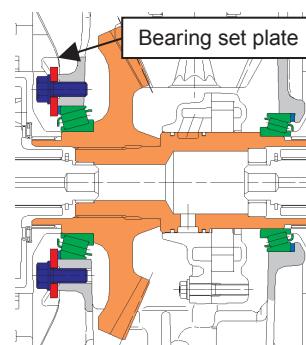


Fig. 4 Developed structure

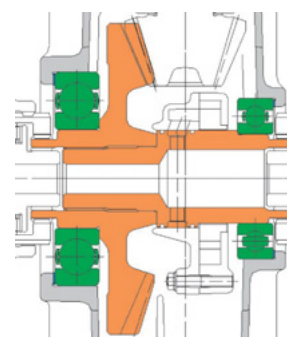


Fig. 5 Previous structure

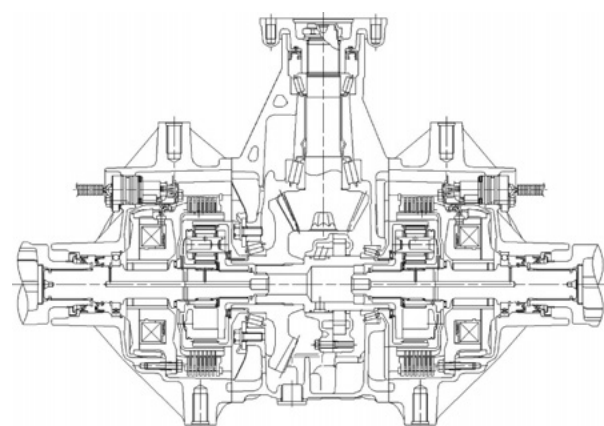


Fig. 2 Cross-section view of newly developed rear differential unit for RDX and MDX

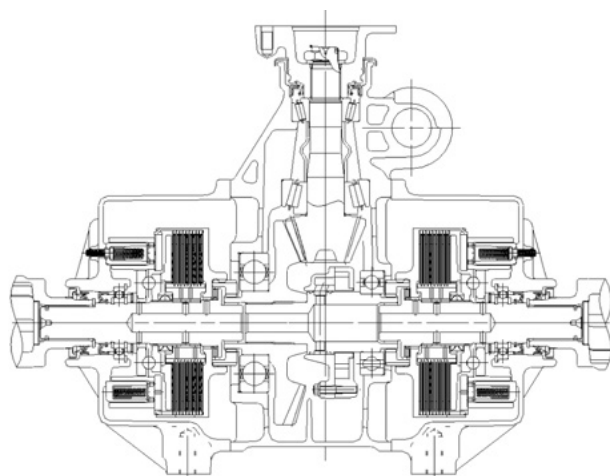


Fig. 3 Cross-section view of previous rear differential unit VTM-4

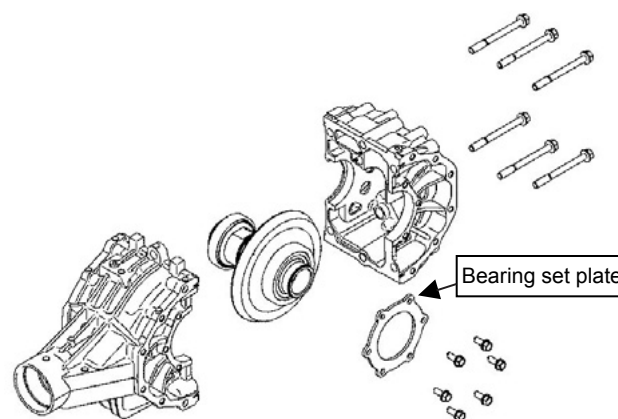


Fig. 6 Developed structure

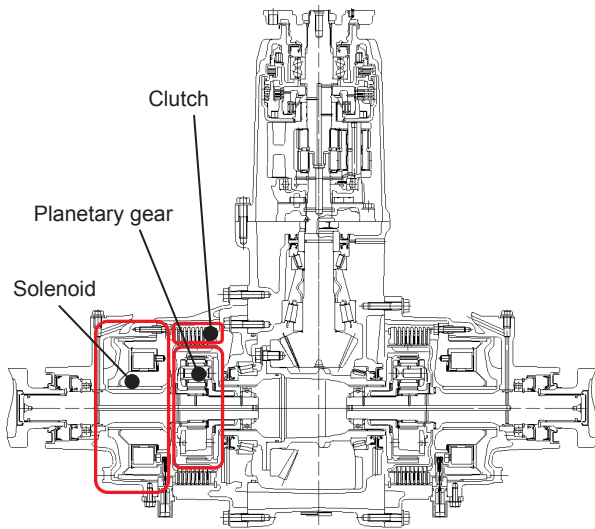


Fig. 7 Cross-section view of rear differential unit SH-AWD for LEGEND

The planetary assembly has three elements: a ring gear, a carrier, and a sun gear. Torque is input from the ring gear and output from the carrier. The output torque can be controlled freely, from zero to the maximum output, by controlling the torque of the remaining element, the sun gear. This mechanism itself is the same as the one that was developed for the previous SH-AWD, but everything except the planetary ratio setting has been newly designed to reduce the size and weight.

This has increased the maximum output torque compared to those of the previous VTM-4 and the SH-AWD.

4. Speed-increasing Ratio Setting

The target application vehicle was determined to be the RDX and MDX in this system development.

These models both fall under the SUV category and are subject to a strong demand for driving performance equivalent to that of a sports sedan as the concept for these vehicles.

However, SUVs generally have a higher center of gravity than sedans, and it is not easy to increase cornering performance. Therefore, the SH-AWD system is positioned as one measure for enhancing cornering performance.

The SH-AWD system must set the internal revolutions of the rear differential unit higher than the front wheel revolutions. This is to apply torque in the drive direction to the rear outer wheel when the turning path of the rear outer wheel is larger than the turning radius at the center of the front wheels⁽¹⁾.

The speed-increasing ratio setting is an important factor in the SH-AWD system, so this was investigated in various driving modes. The results showed that

sufficient merit in cornering performance can be obtained if the rear outer wheel can be driven at a turning radius of 30 m or more. Based on these results, this development set a constant speed-increasing ratio of 1.7%, and eliminated the speed-increasing gear section applied to the previous SH-AWD to perform two-speed shifting. The reason for this setting is that based on the above-mentioned SUV characteristics, the front wheel slip ratio was predicted to increase as the steering angle increased, and this was predicted to increase the actual speed-increasing ratio. The front wheel slip ratio was estimated at 0.8%, and theoretical investigations using this figure, predicted that sufficient performance could be obtained at a speed-increasing ratio of 1.7%. Figure 8 shows the investigation results, and indicates that the rear outer wheel can be driven at a turning radius of 28.4 m or more given a front wheel slip ratio of 0.8%. This supports the requirement confirmed by the above investigation that the rear outer wheel be driven at a turning radius of 30 m or more.

Figure 9 shows these verification results.

Performance was confirmed by actual driving tests over normal paved roads and snow surfaces. The results showed that a front wheel slip of 0.8% or more occurred.

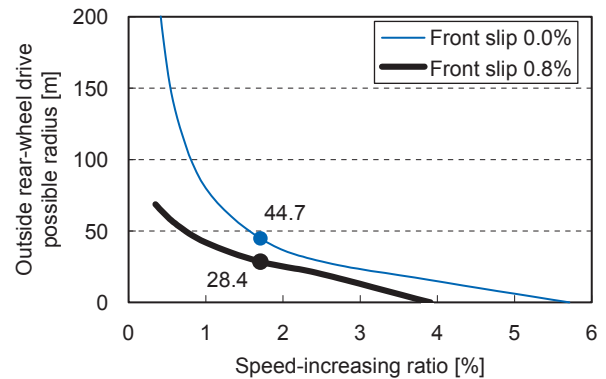


Fig. 8 Relation between speed-increasing ratio and drive possible radius

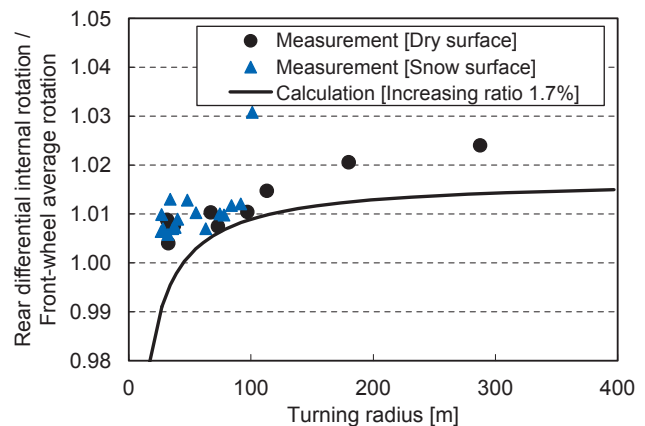


Fig. 9 Measurement result of rear differential internal rotation

The figure was used in the theoretical calculations, and this indicates that the rear outer wheel could be sufficiently driven even at a turning radius of 30 m or less. In this manner, setting the speed-increasing ratio with a focus on the vehicle characteristics made it possible to realize sufficient lateral drive force distribution effects without two-speed shifting by a speed-increasing gear.

As shown above, the SH-AWD speed-increasing ratio is an important factor in determining cornering performance. In addition, it also greatly affects the clutch abrasion described in Section 5, so this must also be taken into account.

5. High μ , Low Abrasion Clutch

The μ value and characteristics of the clutch are pointed out as the element to determine the torque capacity (maximum-output torque) of the rear differential unit. The SH-AWD system clutch constantly performs slip control, so in addition to a high absolute value for μ , low abrasion is also required. This abrasion amount affects the shape of the actuator (hereafter “electromagnetic solenoid”) described in Section 6.

This development not only reviewed the materials of the clutch developed for the previous SH-AWD, but also changed the manufacturing method. This simultaneously achieved both a higher μ value and low abrasion. The specific changes are as follows.

- (1) The facing materials were changed.
- (2) The molding process was changed.

Figure 10 shows the measured μ characteristic values for different slip revolutions. This shows that the μ value increased compared to that of the previous clutch. The important point here is that the μ value increases together with the revolutions. When this characteristic is lost, issues such as vibration and abnormal noise can occur during slip control.

A higher μ value was achieved by optimizing the percentages of the raw material mixture that comprise the facing of the clutch and by increasing the surface smoothness. Increasing the μ value made it possible to

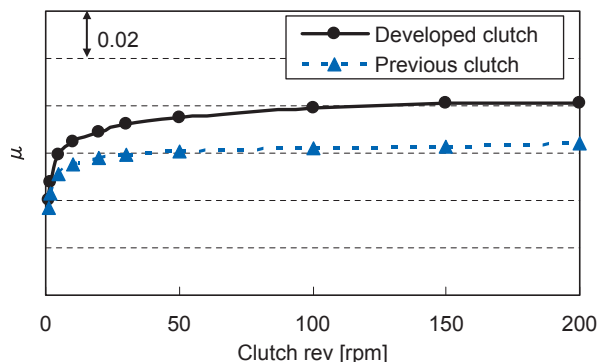


Fig. 10 Clutch μ characteristic

reduce the number of clutch plates, which also reduced the weight and cost.

Abrasion reduction was achieved by changing the manufacturing method to increase the hardness of the friction materials. Figure 11 shows the initial abrasion immediately after the start of use and the abrasion after use equivalent to 240 000 km. Compared to the previous clutch, the newly developed clutch reduced both initial abrasion and durability abrasion.

The clutch-absorbed energy was used to predict the lifetime clutch abrasion. This can be calculated from the output torque and clutch revolutions while running. The absorbed energy when running in a certain mode was converted to the amount of lifetime and was used as the basis for the lifetime abrasion setting.

In addition, abrasion is greatly influenced by the speed increasing ratio described in Section 4, so investigations were also simultaneously conducted from that aspect. Figure 12 shows the results of those theoretical investigations.

The absorbed energy and the speed increasing ratio basically have a proportional relation. However, this relation changes according to the amount of lateral

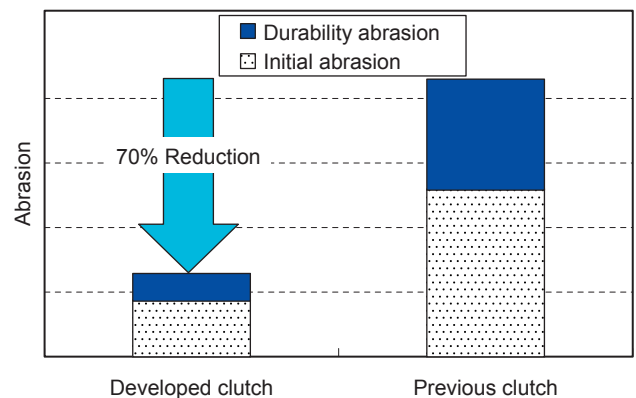


Fig. 11 Abrasion comparison

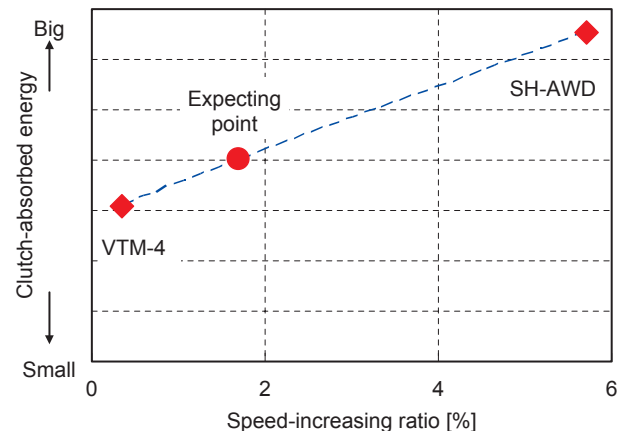


Fig. 12 Relation between speed-increasing ratio and clutch-absorbed energy

distribution control required from the viewpoint of maneuvering stability, so coordination with the vehicle control side is necessary.

6. Actuator Setting

The actuator (hereafter “electromagnetic solenoid”) that controls the clutch uses a flat gap, which reduces both the size and weight by optimizing the speed increasing ratio setting and reducing clutch abrasion. The specific changes are as follows.

- (1) The air gap shape was changed (from tapered to flat).
- (2) The number of main coil windings was changed.
- (3) The number of search coil windings was changed.

The direct electromagnetic clutch, which is a feature of the SH-AWD system, has a structure that controls torque by applying an electromagnetic solenoid attraction force directly to the clutch. The attraction force is inversely proportional to the square of the air gap, so setting a smaller air gap is an effective means of reducing the size and weight, but the air gap cannot be set smaller than the lifetime clutch abrasion. That is to say, the electromagnetic solenoid requires an air gap to generate attraction force, so the attraction force naturally cannot be generated if the clutch becomes worn to the point that the air gap disappears (the yoke and the armature contact each other). This shows that the air gap setting and the clutch abrasion are closely interconnected.

This development reduced the lifetime air gap variation by setting the optimum speed increasing ratio and developing a low abrasion clutch. As a result, the shape of the electromagnetic solenoid air gap was changed from a tapered shape to a flat shape, which resulted in a significant reduction in size. Figure 13 shows a cross section of the developed and previous electromagnetic solenoids at the same scale. The red bold lines in the figure indicate the air gap.

As mentioned previously, the characteristics of the electromagnetic solenoid are such that the attraction force changes with the air gap. However, slip control is constantly performed, so the clutch thickness that

determines the air gap experiences abrasion, albeit at an infinitesimal rate. This means that the air gap changes, so the attraction force and thus the clutch torque also change. The magnetic-flux detection system detects this change and corrects the current value applied to the electromagnetic solenoid⁽²⁾. The magnetic-flux detection system used in this development is based on the previous SH-AWD, but changing to a flat air gap made it necessary to enhance the magnetic-flux detection accuracy. Both the number of search coil windings and the detection current were increased, resulting in a magnetic-flux detection accuracy increase of 20%. The control performance equivalent to the previous actuator was achieved by these measures.

7. Results

The following results were obtained with respect to the development goals of “enhancing cornering performance” and “the simultaneous achievement of higher output, smaller size, and lighter weight.”

7.1. Enhanced Cornering Performance

The performance of a vehicle equipped with the newly developed rear differential unit and a first-generation MDX were compared on a normal dry road, snow-packed road, and dirt road surfaces. The results show that the development concept of “enhanced cornering performance” was achieved (Fig. 14).

7.2. Simultaneous Achievement of Higher Output, Smaller Size, and Lighter Weight

Figure 15 compares the maximum output. The newly developed unit achieved 10% higher output compared to the VTM-4 mounted in the previous vehicle.

Figure 16 compares the weight. Here as well, the newly developed unit achieved a weight reduction of 5% compared to the VTM-4.

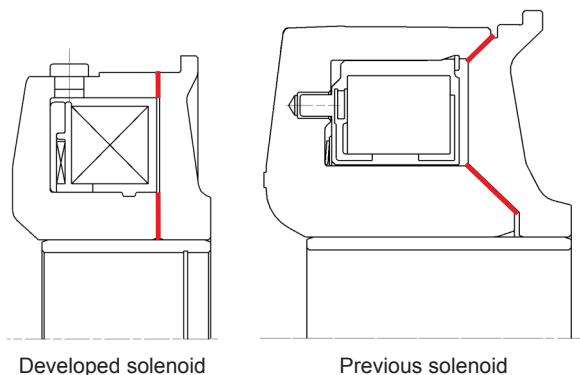


Fig. 13 Cross-section of electromagnetic solenoid

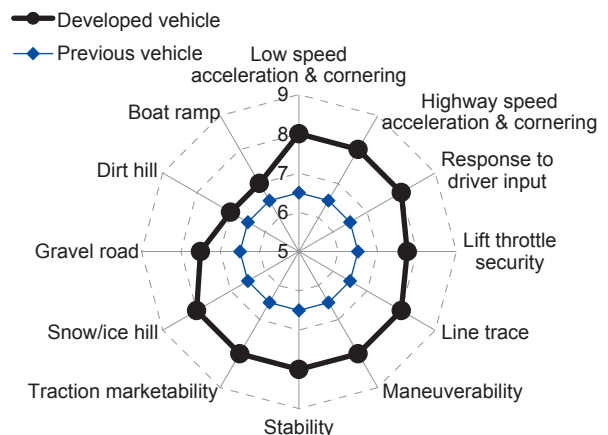


Fig. 14 Evaluation value

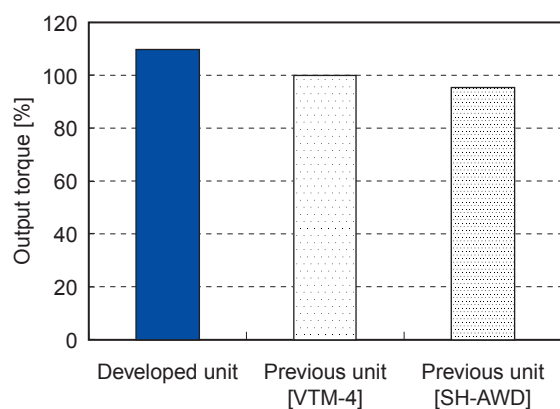


Fig. 15 Output torque comparison

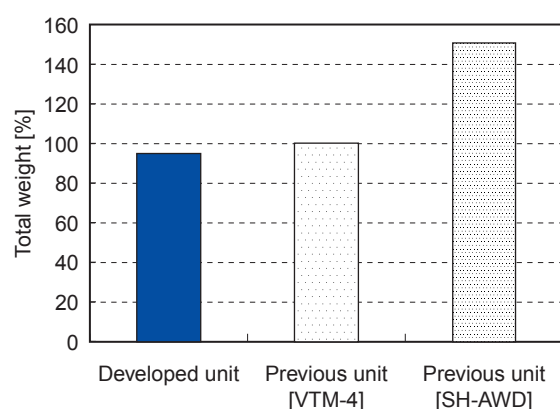


Fig. 16 Weight comparison

References

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- (2) Kunii, R., Kanno, Y., Iwazaki, A., Sekiya, S.: Control Technology of Direct Electromagnetic Clutch Employed in SH-AWD System, Honda R&D Technical Review, Vol. 17, No. 2, p. 20-25

8. Conclusion

- (1) Focusing on the vehicle characteristics and the tire slip rate, the turning radius at which the rear outer wheel can be driven was predicted to be 28.4 m at a speed-increasing ratio of 1.7%. In addition, the accuracy of this figure was verified through actual driving tests.
- (2) The optimum settings were made for an SUV vehicle based on free control of the four-wheel driving force developed for the LEGEND. This enhanced performance over all operating ranges compared to the previous vehicle.
- (3) Capacity increasing measures centering on the newly developed clutch increased the output by 10% compared to the rear differential unit mounted in the previous vehicle.
- (4) By setting the optimum speed-increasing ratio to reduce the clutch-absorbed energy, the electromagnetic solenoid weight was reduced. This achieved a 5% weight reduction compared to the previous rear differential unit.

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