

Development of 4WD System for Minivan

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ABSTRACT

A torque on demand 4WD system has been developed with a front engine front drive vehicle as a base to balance traction performance and handling characteristics with fuel efficiency in a minivan. The response of torque to front-rear wheel rotation speed difference was studied to ensure traction performance and handling characteristics. The use of an initial torque between the front and rear wheels was considered as a method of improving the response of torque transmitted to the rear wheels when the front wheels slip. Using the Honda dual pump system as a reference, the results of calculations of the required traction force on snow and actual measurement values for tire traction characteristics were employed to find the optimal torque characteristic. As a result, 25% of maximum necessary torque was established as the ideal initial torque. A comparison of the optimal torque characteristic with the torque characteristic of the dual pump system in a simulation of a vehicle starting on snow confirmed the effectiveness of the initial torque. It was possible to achieve the optimal torque characteristic with a simple mechanical structure. A one-way cam and a preset pilot clutch were added to the rear final drive unit of the dual pump system. Good fuel efficiency was ensured through setting an appropriate gear ratio for the rear final drive unit. As a result, the newly developed minivan 4WD system meets vehicle performance requirements while weighing only 54 kg, making it the lightest in its class.

1. Introduction

In recent years, through ease of use for both every day and leisure purposes, the minivan, which can hold a lot of people, has become quite popular in Japan. Passenger cars with front engine front drive, with their large interior and comfortable ride, are used primarily as the base structure for minivans. A 4WD system developed for a minivan needs to be lightweight, compact, and not a detriment on fuel efficiency as well as being able to provide traction force according to changes in the number of people riding in the vehicle. This report discusses a minivan 4WD system developed for satisfying these types of needs.

2. Development Goals

The number of people in the vehicle changes more significantly for minivans than for passenger cars. The minivan has a higher center of gravity. The change in vertical load on the front wheels, depending on driving conditions, can also be larger⁽¹⁾. Because of this, if the road surface is slippery the front wheels tend to slip, making it more difficult to help ensure traction when starting and handling while turning. In order to help ensure the vehicle's traction force, improving the response of transferring torque to the rear wheels has been considered. An electronically controlled system could provide such response; however, it would require sensors, an ECU, etc., making the system more

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complex, which could be a detriment. A full time 4WD system can address this issue, as torque is being transferred to the rear wheels continuously. This type of system requires a central differential and much more durability, as torque is continuously being transferred to both front and rear wheels. This leads to the difficulty of meeting size and weight requirements and improving the vehicle's fuel efficiency. Therefore, the current development has focused on a lightweight, compact, simple 4WD system intended for a minivan. This has been done by developing the idea of a passive torque on demand 4WD system (hereafter, passive 4WD system) that transfers torque to the rear wheels in proportion to the front/rear wheel rotation speed difference. Building on this idea, through simulation, the torque characteristics which best meet the following two requirements have been pursued.

- (1) Ability to ensure traction performance and handling characteristics when driving on snow that is the same as an electronically controlled 4WD system.
- (2) Maintain the same fuel efficiency as a 4WD system for passenger cars.

3. Investigation of the Optimal 4WD Torque Characteristics

The Honda Dual Pump System⁽²⁾ (DPS) will be explained and will be used for the basis of this passive 4WD system. For a passive 4WD system, a consideration is to have an initial torque defined between the front and rear wheels as a method for improving the response of torque transfer to the rear wheels. In order to determine the preset torque, a 2 400 cc class minivan was used as an example for slope starting on snow. As can be seen in Fig. 1, investigation of the required traction force of the model was performed.

In Fig. 2, the calculation of the required traction force for driving on snow and the measurements of the front tire traction force characteristics are shown, and the area where need of required traction force at the rear wheels can be seen. This is converted to the torque characteristics of the front/rear wheel rotation speed difference in the DPS system (hereafter torque characteristics), and they are both shown together in Fig. 3. It was found that the area in which the DPS torque characteristics was insufficient could be covered by the addition of an initial torque in the amount of 25% of the maximum DPS torque transfer. The initial torque was set such that it does not interfere with the torque limit function⁽³⁾ set where unneeded torque was cut to lighten the system. It was also set so that it did not interfere with the area where tight corner braking torque is needed. In this way, the optimal torque characteristics were determined.

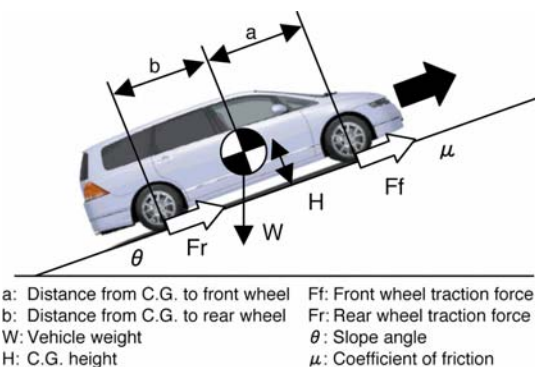


Fig. 1 Study model

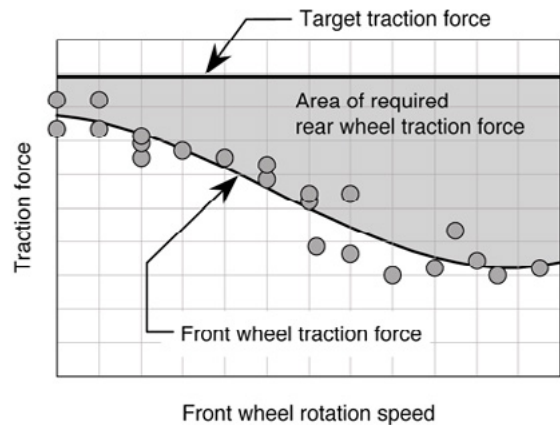


Fig. 2 Tire traction force characteristic on snow

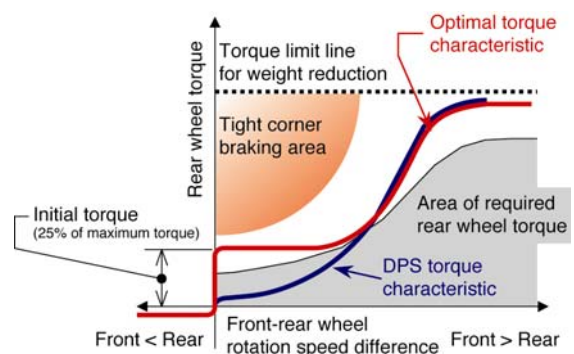


Fig. 3 Torque characteristic

Next, the effect that DPS torque and optimal torque characteristics have on starting performance on snow was confirmed through simulation. This confirmation was performed as defined by the 4WD vehicle model of Fig. 4 showing the coupling between the front and rear wheels and the 4WD system model of Fig. 5 that shows the coupling characteristics used to set the torque characteristics. As a result, through a characteristic of the DPS torque the torque on the rear wheels is delayed and there is a drop in the acceleration of the vehicle, as shown in Fig. 6. Figure 7 shows the characteristics of optimal torque, where the raise in torque is fast, leading to a smooth acceleration when starting.

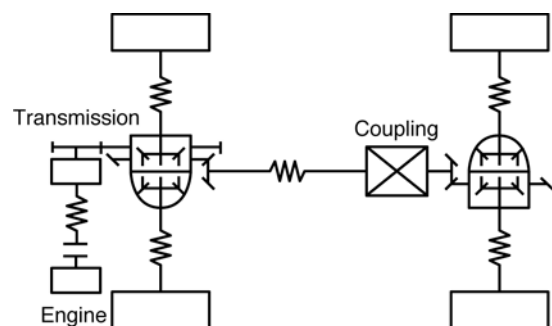


Fig. 4 Vehicle model

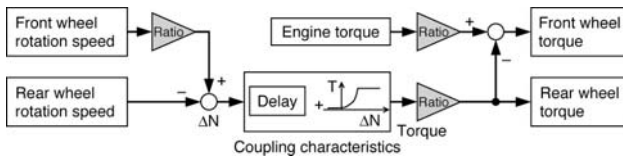


Fig. 5 4WD system model

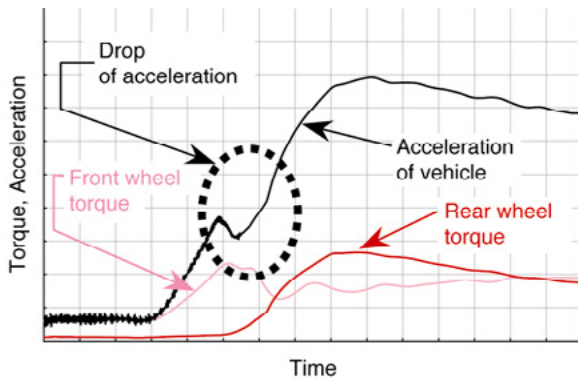


Fig. 6 Simulation data for DPS torque characteristic when starting on snow

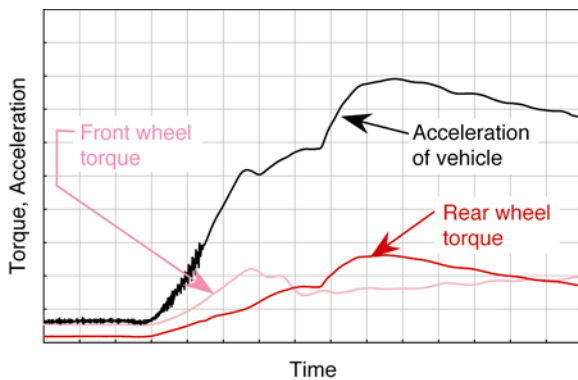


Fig. 7 Simulation data for optimal torque characteristic when starting on snow

4. 4WD System

The system structure diagram for this development is shown in Fig. 8.

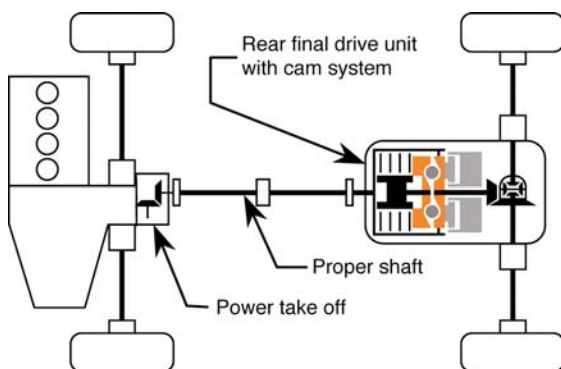


Fig. 8 4WD system

4.1. Rear Final Drive Unit

For the rear final drive unit of passive 4WD systems, other than DPS, there are the viscous coupling and the direct hydraulic pressure torque transfer coupling⁽⁴⁾. Both of these systems pose concerns: the viscous coupling system does not provide very much freedom for control, and the hydraulic system requires the system to be quite large in order to provide sufficient torque. In the current development a preset torque was added to a DPS system that uses a multi-plate clutch for transfer of torque. When transferring the torque, the multi-plate clutch is engaged by a hydraulic mechanism that responds to the front/rear wheel rotation speed difference. By using this type of simple mechanical structure, it was possible to achieve optimal torque characteristics. As can be seen in Fig. 9, the mechanism used to add initial torque consists of a pilot clutch that provides a constant torque and a one-way cam structure that engages a clutch only at times of acceleration. As can be seen in Fig. 10, this one-way cam structure responds to slight differences in the angle of the reference cams between the front and rear wheels, at the time of acceleration. The ball rolls against the cam surface, instantly engages the clutch and transfers the preset torque. And during braking, even if there is a difference in the reference cam angle, the ball hits a vertical wall and does not develop any engaging force, maintaining compatibility with the ABS system. The measurements of the torque characteristics of the newly developed rear final drive unit and a DPS system are compared in Fig. 11.

It was possible to make the size of the newly developed rear final drive unit the same as the rear final drive unit of the DPS system by placing the added components effectively, optimizing the BRG size, and reducing the overall length of the pump and hydraulic controls.

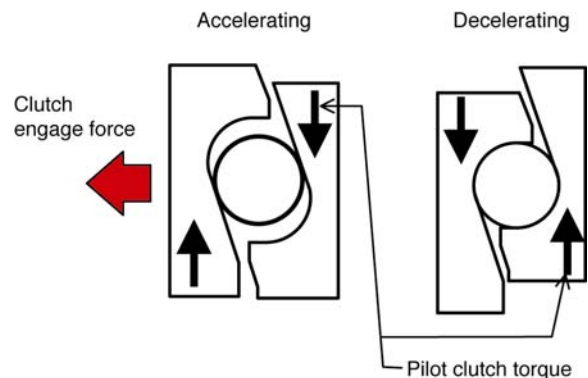


Fig. 9 Working of cam

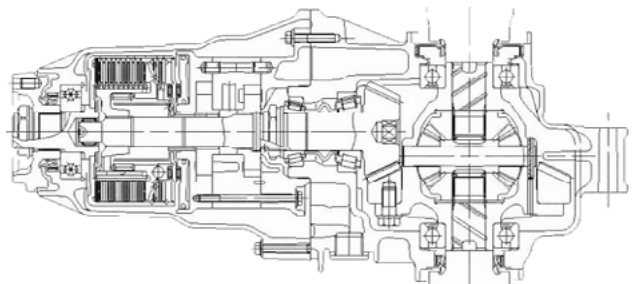


Fig. 10 Sectional view of rear final drive unit

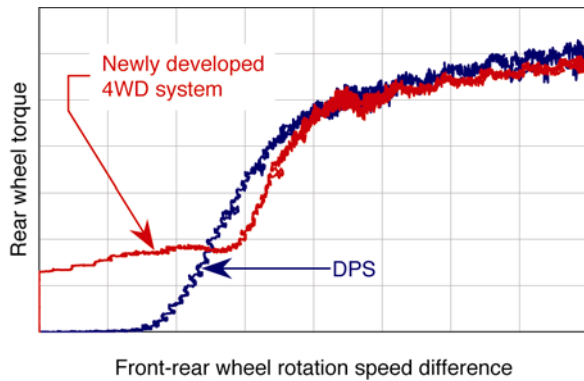


Fig. 11 Torque characteristic

4.2. Fuel Efficiency

In the DSP system, torque transmitted to the rear wheels is reduced during normal driving in order to lower fuel efficiency and weight. Therefore, the amount of friction torque is not changed when the ratio in the front/rear wheel rotation speed difference is about 1%. After increasing the response of the torque transferred to the rear wheels, as can be seen in “Modified 1” of Fig. 12, even when there is a small difference in the ratio of the front/rear wheel rotation speed difference, an increase in friction torque delivered to the rear wheels occurs, leading to an increase in friction torque which leads to the issue of a reduction in fuel efficiency. In order to resolve this issue, the ratio between the gear ratio from the front wheels to the propeller shaft and the rear final drive unit gear ratio was reviewed. The gear ratio that generates the front wheels cam structure input rotational speed was set to be roughly 0.5% lower than that of the rear wheels during normal driving. Therefore, the clutch does not cause engaging force, during normal driving, and has the characteristics shown in “Modified 2” of Fig. 12. Through this change, it was possible to reduce the absolute value of the friction torque, for the rear wheels, to that of the DPS system. This gear ratio setting does not have an effect on the systems response as it has been set on the operation side of the cam mechanism when driving in snowy conditions where the slip ratio of the front wheels is such that 4WD is needed.

4.3. System Weight

The weights of the 4WD system developed at this time for application to the 2004 model Odyssey is compared to other models in Fig. 13. Preserving a feature of the DPS

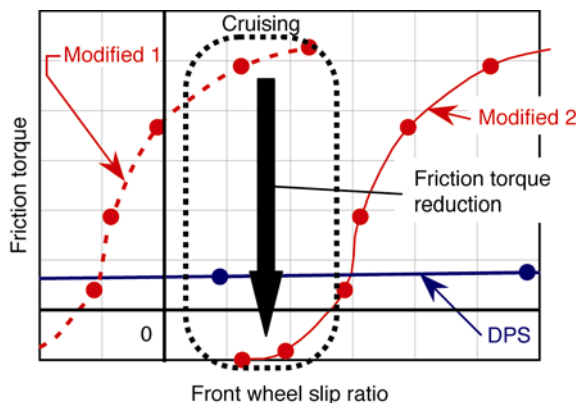


Fig. 12 Friction torque when cruising

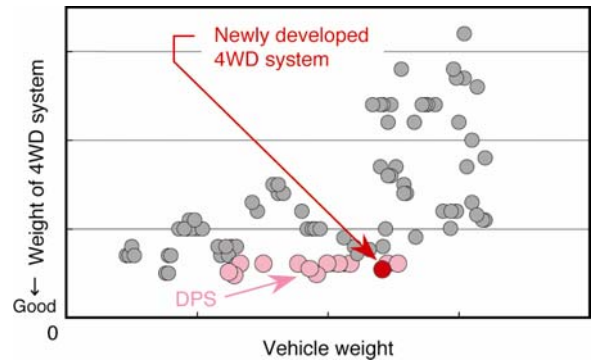


Fig. 13 Weight of 4WD system

system this 4WD system weighs only 54 kg, achieving the lightest in its class.

5. Vehicle Performance

5.1. Traction Performance on Snow

As can be seen from the data showing acceleration from a start on snow in Fig. 14 and the data showing climbable grade in Fig. 15, the traction performance of this system is better than that of the DPS system and has achieved the same traction performance as an electronically controlled 4WD system.

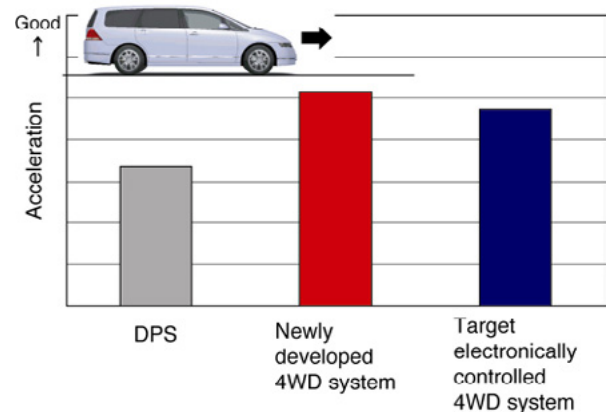


Fig. 14 Starting performance on snow

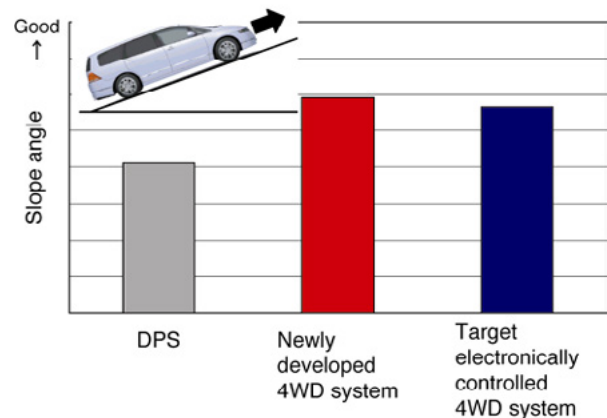


Fig. 15 Slope starting performance on snow

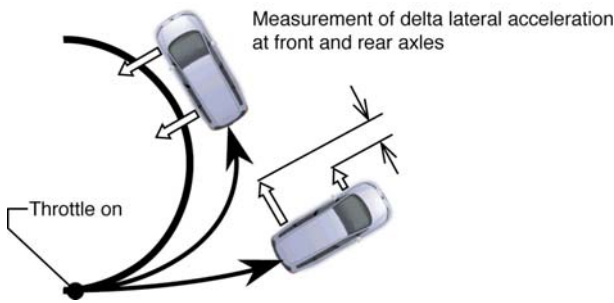


Fig. 16 Cornering test mode

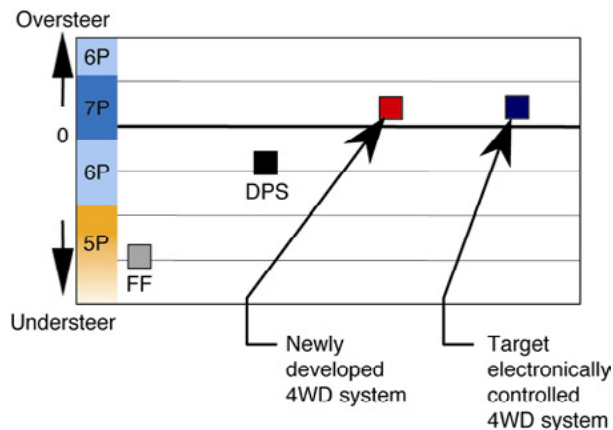


Fig. 17 Cornering performance on snow

5.2. Handling in Snow

In the test mode described in Fig. 16, the results of the handling evaluation are, as shown in Fig. 17, that this system has maintained the same handling performance as that of an electronically controlled 4WD system.

5.3. Running Resistance

A fuel efficiency parameter that is affected is running resistance while coasting. As described in Fig. 18, the running resistance of this system has been held to the same level as the DPS system.

The reported fuel efficiency in the catalog of this system shows that it has achieved the same fuel efficiency as that of a DPS system and is shown in Fig. 19.

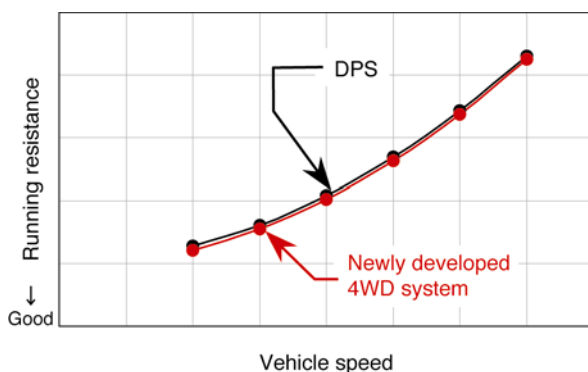


Fig. 18 Running resistance

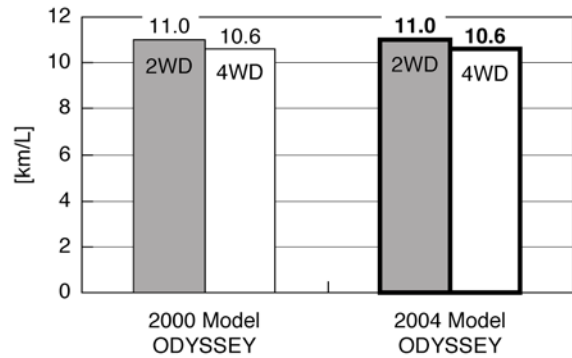


Fig. 19 Fuel efficiency

6. Conclusion

A 4WD system developed for a minivan needs to strive to maintain its traction performance and handling characteristics. Focusing on the torque response of a passive 4WD system, while calculating the required traction force on snow and the actual tire traction force, an optimal torque characteristic was sought. The following are the results of this development:

- (1) Through combining the characteristics of DPS torque and an initial torque of 25% of the maximum required torque, this system achieved optimal torque characteristics. It was also shown to be effective, through simulation, when the vehicle starts on snow.
- (2) In order to show that optimal torque characteristics had been achieved, the system was installed on a minivan where it achieved the same traction performance and handling characteristics on snow as a minivan with an electronically controlled 4WD system installed.
- (3) The friction torque during normal driving was developed to be the same as the DPS system, and it has achieved the same level of fuel efficiency as the DPS system.
- (4) This system has balanced traction performance and handling characteristics with fuel efficiency while being in a package that weighs 54 kg, the lightest in its class.

This system has been implemented on the 2004 model Odyssey. Honda started to sell this model in Japan in October of 2003 and positive feedback has already been received from customers.

References

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