

Development of Parking Lock System Behavior Analysis

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ABSTRACT

Parking lock can occur when a driver inadvertently puts the automatic transmission lever into park while the vehicle is in motion. Prediction technology was developed to determine specifications that could help prevent the occurrence of parking lock. In order to understand the phenomenon and increase prediction accuracy, gap sensors were used to measure the behavior of the component elements of the parking lock device in an actual vehicle and parking lock was reproduced in a vehicle moving at high speed. In the prediction, multibody dynamics analysis was used to take into account collisions between component elements. The prediction accuracy was increased by identifying the restitution coefficient and the spring damping force. As a result, it was possible to predict the specifications that could help prevent parking lock from occurring while taking into account various layout restrictions at the investigation stage.

1. Introduction

Since automatic transmissions continue to become more compact and more economical, it has become necessary to cope with the reduced diameter, the parts sharing, and the diversification of part layouts in the parking lock device. It is also necessary to determine specifications in a short period of time due to the shorter development period.

Parking lock devices are intended to lock the drive system when the vehicle is stationary, however it is necessary to prevent the drive system from locking when the driver inadvertently shifts the gear into park while the vehicle is in motion. Previously, a qualitative trend of whether locking occurs or not when specifications are changed was already studied and the final specifications were matured by checking them through repetitive tests. But the tests need to be performed on an actual vehicle, and a large number of man-hours are required to check the large number of specifications. So it was necessary to develop a technology that could predict whether locking would occur with changes in specifications.

There is a report about the internal phenomena when a driver puts the lever into park while driving using prediction technology⁽¹⁾.

However, this technology was not intended for reproducing locking, but only for understanding the qualitative trend concerning the collision between the parking gear and the parking pawl.

In the development of the parking lock device, measurement technology for understanding the high-speed behavior of the component elements and prediction technology based on multibody dynamics analysis were developed. As a result, it was possible to quantitatively understand the effect of changing the specifications, enabling more efficient development of the device. The results are described below.

2. Development Goals

2.1. Description of the System

Figure 1 shows the position selector of the automatic transmission. The selector consists of a select lever on the driver side, a control shaft on the transmission side, and a wire joining these two components. The operation of the lever rotates the control shaft via the wire. The control shaft directs the parking lock device that mechanically locks the drive system when the select lever is put in the parking position (hereafter called the “P position”).

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The parking lock device is shown in Fig. 2. Honda adopts a lever-type mechanism on many of its models, as opposed to the cone mechanism used by other manufacturers. The motion of the parking brake lever (hereafter called “lever”) operates the parking pawl (hereafter called “pawl”) via a roller. The pawl engages with the gear, causing the drive system to lock. When the lever is in a position other than P, the pawl is pushed against the rotational control stopper side by the pawl spring. Also, to enable the lever to move to the P position regardless of the phase of the parking gear (hereafter called “gear”) when the vehicle is stationary, the lever is connected to the control shaft via the torsion coil spring as a waiting mechanism, as shown in Fig. 3.

2.2. Putting the Lever in the P Position while the Vehicle is in Motion

If the driver inadvertently puts the lever in the P position while the vehicle is in motion, the pawl of the parking lock device connected directly to the lever will attempt to engage with the rotating gear that is driven by the tires. However, the pawl will be repelled by the gear due to the abovementioned waiting mechanism, preventing engagement and thus preventing parking lock from occurring. Yet, it has been known from tests carried out during the development stage that if the setting of the specifications of the parking lock device is not appropriate, parking lock can occur at relatively high speeds.

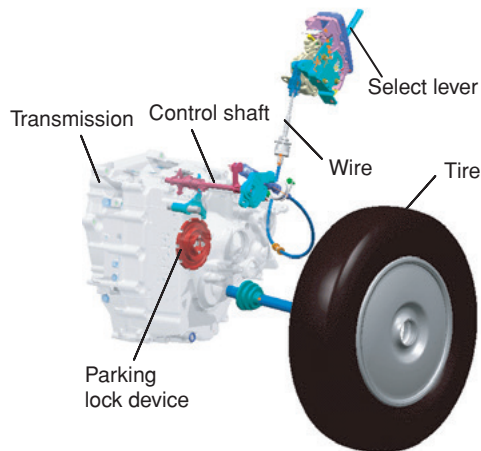


Fig. 1 Position selector

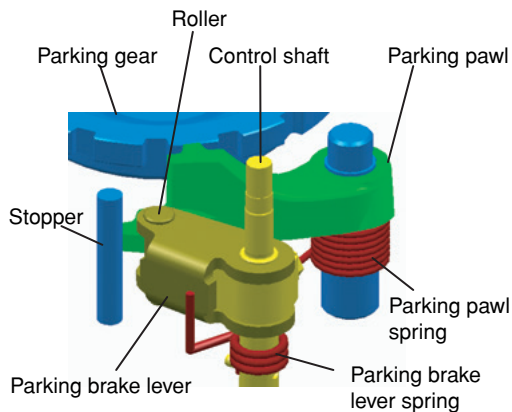


Fig. 2 Components of parking lock device

2.3. Issues Concerning Conventional Development Methods

Previously, the effect of changing the various specifications, including the number of teeth on the gear, the tooth space width, the chamfer angle, the angle and the corner size of the pawl ratchet, and the lever spring load were checked in tests that involved shifting the lever to the P position while the vehicle was in motion. The specifications were determined based on the results, however the effect of changing the various parameters in the parking lock device was not measured quantitatively. These parameters affected each other, so it was necessary to carry out a large number of tests in order to determine the specifications that would satisfy the requirements.

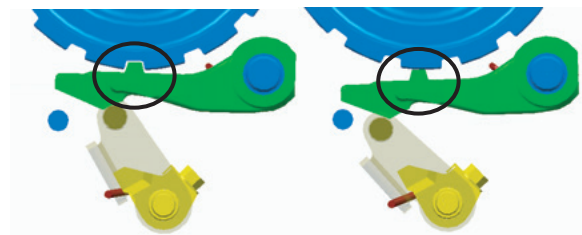
The tests have not been carried out on a bench but on an actual vehicle because of differences in the inertial mass and stiffness of the drive system. The only measurements performed were vehicle speed and acceleration, so it was not practical to evaluate the effectiveness of different specifications.

For this reason, it was necessary to devise a measurement method that would allow the effectiveness of different specifications to be evaluated. Devising the method required the establishment of a measurement technology that could identify the motion of the component elements of the parking lock device inside the transmission of an actual vehicle.

It was also necessary to develop prediction technology in order to cope with the size reduction and sharing of the component parts, along with the increasing compactness and reduced cost of an automatic transmission, the diversification of layout shown in Fig. 4, and the shorter development period.

Accordingly, development was carried out with the following goals.

- (1) Investigation of the mechanism of a parking lock in a moving vehicle
- (2) Development of technology for predicting parking lock in a moving vehicle



(a) Locked state

(b) Unlocked state

Fig. 3 Position of parking pawl and parking gear

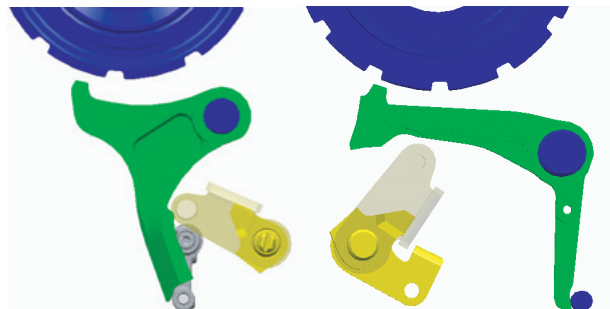


Fig. 4 Variations of parking lock devices

3. Testing and Analysis Technology

A method of measuring the behavior of the component elements of the parking lock device in the transmission of an actual moving vehicle when the lever is put into the P position was developed. As a result, it was possible to reproduce the mechanism that caused parking lock to occur while the vehicle was in motion and also quantitatively understand the effectiveness of each parameter.

3.1. Selection and Layout of the Sensors

The measurement items are the rotational behavior of the pawl, lever, gear, and control shaft, which are component elements of the parking lock device. When the lever is put in the P position while the vehicle is in motion, each element moves at extremely high speed. Therefore, it was necessary to devise a measurement method that responded quickly. This method also needed to permit high-resolution measurement of the rotation angle in order to quantitatively evaluate the engagement of the pawl with the gear. In addition, because measurement is performed on an actual vehicle rather than on a bench, the sensors had to be installed inside the transmission. Given these requirements, miniature gap sensors (eddy current type sensors) that have fast response times and high resolution were used.

Figure 5 shows the layout of the sensors in the transmission. The behavior of the pawl was measured by converting the distance detected by the gap sensors installed in the direction of rotation into an angle. The rotation angle of the lever without a stopper is large and the sensors cannot be installed in the direction of rotation, so the side of the lever was cut to make inclined face. The sensors

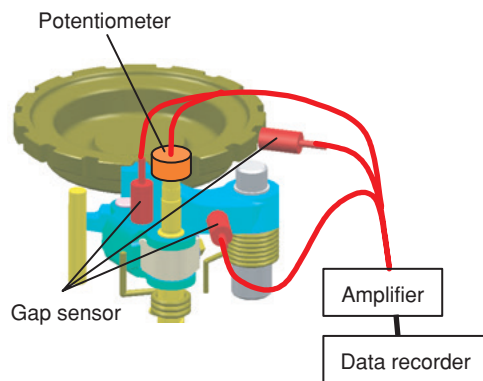


Fig. 5 Sensor layout inside transmission

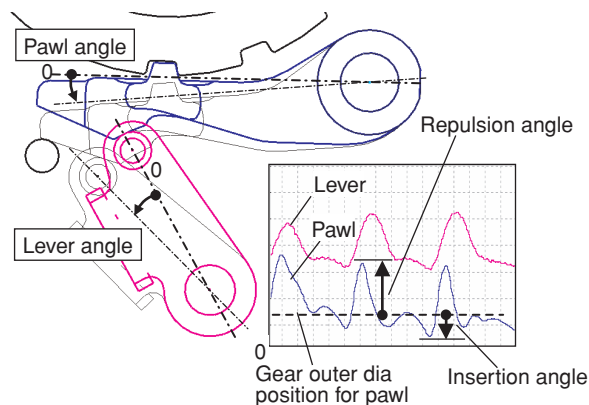


Fig. 6 Definition of pawl and lever angles

were installed in the direction perpendicular to rotation and measurements were performed. The phase of the tooth space of the gear was measured. Because the control shaft passes through the case to the outer side, its rotational angle was measured from outside using a rotary encoder. Figure 6 shows the definition of each angle of rotation and an example of the output. The angle of rotation in the locked condition when the lever is put in the P position is defined as 0.

3.2. Measurement Results

The rotational behavior of the lever and the pawl was measured using this method when the lever was put in the P position while the vehicle was in motion at a specified speed and those behavior after the lever was put in the P position until the vehicle stopped are shown in A of Fig. 7. The pawl and the gear collided with each other several thousand times. It was found that in a certain vehicle speed range (hereafter called “synchronized area”), the degree of engagement of the pawl and repel of the lever are extremely large. The behavior at each vehicle speed range is examined below.

Part B of Fig. 7 indicates the behavior during a period of 0.1 sec in the synchronized area. Rotation of the pawl is restricted between the stopper and the gear, so the pawl goes and returns between them due to being repelled by the gear. The lever is repelled by the pawl without rotational restriction, so the lever rotates largely. Consequently, the rotational behaviors of the lever and pawl are different and the lever is not driven together with the pawl.

Part C of Fig. 7 indicates the behavior during a period of 0.1 sec at a vehicle speed that is lower than the synchronized area. The rotational angle is lower and the motion of the pawl and the lever are the same, so the lever and pawl are driven together without separating from each other.

Figure 8 shows the measurement results of different specifications. Under these specifications, there is not a synchronized area, and the gear and pawl are driven together throughout the entire range.

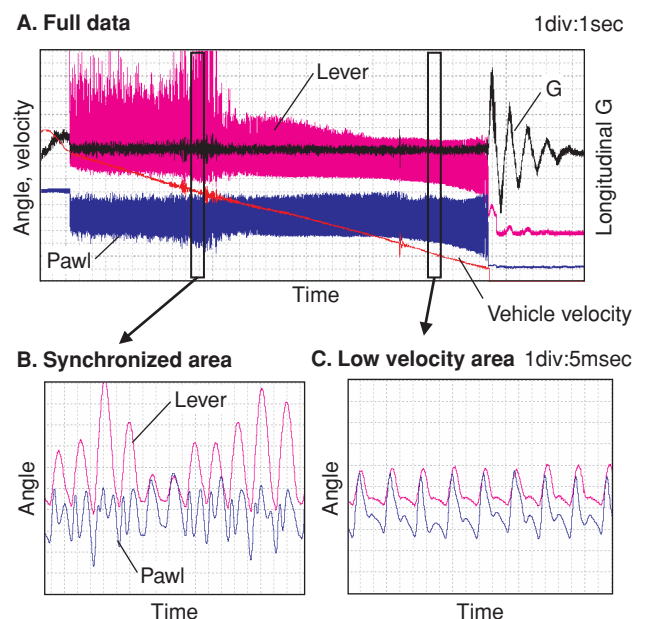


Fig. 7 Example of measurement result

3.3. Examination of the Repelling Behavior

There are two main reasons why the degree of repel differs according to the specifications and vehicle speed. The first is the contact angle of the pawl ratchet against the gear and the contact angle of the pawl against the roller of the lever, which determines the degree of repel. The degree of repel of the pawl depends upon the collision angle and the collision speed with the gear. For example, if the corner of the pawl ratchet collides with the chamfered part of the gear, as shown in A of Fig. 9, the collision angle will be large, therefore the component of the collision speed in the vertical direction at the collision face will be large, so the degree of repel will also be large. Conversely, if the end of the pawl ratchet collides with the chamfered corner of the gear, as shown in B of Fig. 9, the collision angle will be small, therefore the component of the collision speed in the vertical direction at the collision face will be small, so the degree of repel will also be small. Likewise, the degree of repel of the lever also depends upon the collision angle between the pawl and the roller of the lever.

The second reason is the number of tooth spaces, which determines the timing. If the pawl is repelled by the gear and then directly enters the tooth space when it returns to the gear, the degree of engagement will be larger than for the case where the pawl slides against the outer periphery of the gear, resulting in an extremely large degree of repel.

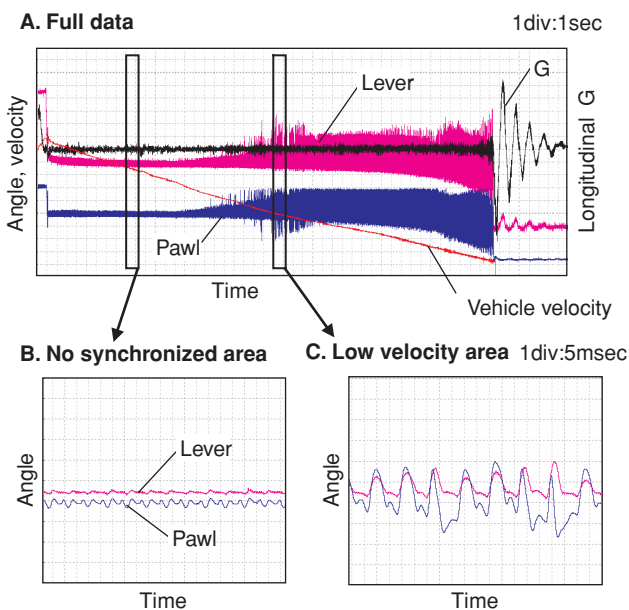


Fig. 8 Measurement result of other variation

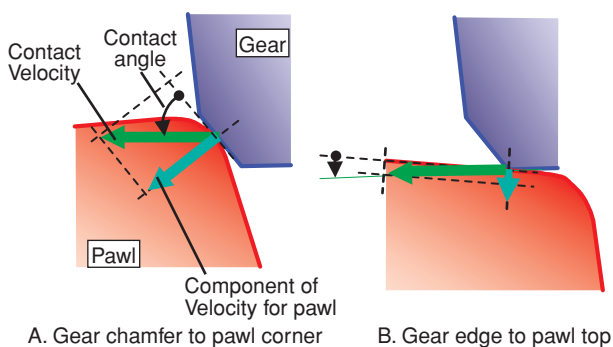


Fig. 9 Contact between gear and pawl

3.4. Mechanism of Parking Lock in a Moving Vehicle

Figure 10 shows the change in the collision angle of the lever with respect to the rotational angle of the pawl (degree of gear engagement). Parking lock occurs when the gear is unable to repel the pawl. This situation occurs if the roller goes past the corner on the lever side of the pawl, causing the collision angle to change greatly and virtually preventing a motion component in the rotational direction of the lever from being generated, as shown in B of Fig. 10.

However, when the vehicle is moving at high speed, the time during which the tooth space remains open for engagement with the pawl is short. So while the lever and the pawl are being driven together, the pawl cannot engage with the gear to the bottom of the tooth space under the push-in force of the lever.

In order to reproduce the mechanism by which the pawl engages with the gear to the abovementioned position in a vehicle traveling at high speed, the internal behavior when parking lock occurred was measured using specifications that were found to facilitate locking during the development process. Figure 11 shows the behavior up to several milliseconds prior to when locking occurs. The broken lines in the figure show timelines of gear tooth space, the figure in the frame of bold line shows behavior of a moment of locking, and behavior of this time is illustrated. When the return cycle of the pawl starts to match the gear tooth space cycle, the

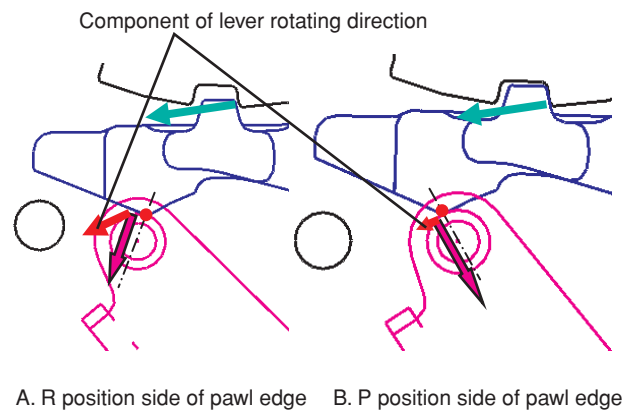


Fig. 10 Relation between lever and pawl

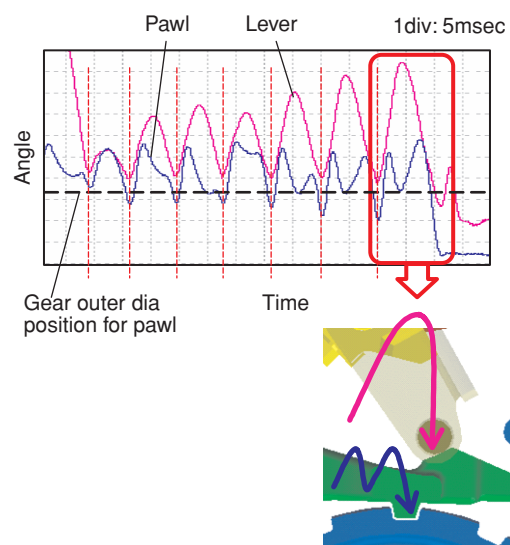


Fig. 11 Parking lock at high speed

degree of repel between the pawl and the lever becomes large. If the return cycle of the lever is also synchronized with this cycle, the pawl will be pushed to the bottom of the gear tooth space at high speed causing parking lock to occur.

As a result of measurement, the factors that greatly affected the mechanism were the rotational speed of the gear, the number of gear teeth, the lever spring load, the collision angle between the gear and the pawl, and the collision angle between the pawl and the lever.

4. Prediction Technology

Based on the characteristics obtained from measurement, a prediction model was constructed by multibody dynamics analysis. This model predicted the occurrence of parking lock when the lever was put in the P position during motion for different specifications.

4.1. Construction of a Prediction Method

From the measurement results obtained in Section 3.2., it was found that internal behavior was extremely complex, and was nonlinear due to the collective effect of the behavior of one component on the others. Consequently, in order to predict the occurrence of parking lock in a moving vehicle, it was necessary to reproduce this behavior taking into account the restriction on rotation and also the collision between the components. Accordingly, multibody dynamics analysis that permitted computation of the collision and rotational behavior at high speed was used.

Figure 12 shows the model used for the prediction. Although it is necessary to take account of the vehicle itself when creating a model for parking lock in a moving vehicle, the contribution analysis enables the model to be simplified to only the vicinity of the parking lock device and the moment of inertia of the drive train.

In the model, collision between each component is taken into account. In order to cope with the various conceivable collision forms, such as corner/face to face/corner, particularly in the case of a collision between the pawl and the gear, contact elements that can compute the contact between curved faces were used. When modeling was carried out, a very small radius was added to pin corners such as chamfered faces of the gear in order to avoid computation errors during the analysis.

Measurement revealed that when the pawl engaged with the gear, torsion was generated in the drive train resulting in a fluctuation of

rotational speed on the gear side. For this reason, the moment of inertia on the gear side was coupled to the moment of inertia on the tire side by a spring that was equivalent to the torsional rigidity of the drive train. The equivalent moment of inertia of the body was added to the tire side.

Similar to measurement, in analysis an initial rotational speed is given to the gear and tires, speed is reduced using a torque, the control shaft is rotated to the P position, and the behavior of parking lock in a moving vehicle is reproduced.

From the predicted results that are computed until the gear stop, the occurrence of parking lock is judged according to whether or not the engagement of the pawl corresponds to the position indicated in Section 3.4. above.

4.2. Increased Prediction Accuracy

4.2.1. Identifying the damping coefficient of the lever spring

The damping generated by the lever spring is due to friction between the spring coils and sliding between the spring and the shaft or lever. Because the damping depends upon velocity, it greatly affects the suppression of repelling behavior in this high-speed mechanism and it is essential to identify this damping in order to carry out predictions. It is necessary to identify this damping at a speed corresponding to the actual repelling condition, but because this speed is very high it is challenging to reproduce the specifications on an individual parking lock device. For this reason, a strain gauge was installed on the control shaft and the torque generated in the lever spring was measured when the lever was moved to the P position while the vehicle was in motion. The spring force computed from the measured angle of rotation and spring rate was subtracted from the abovementioned measured value, enabling the damping force and, in turn, the damping coefficient to be obtained.

4.2.2. Identifying the coefficient of restitution

The coefficient of restitution, which is taken into account in collision behavior, was obtained by performing a collision test on each individual component and reverse-computing the behavior by prediction. The value obtained was lower than the general value and it is supposed that it includes the effect of other parts of the system as well.

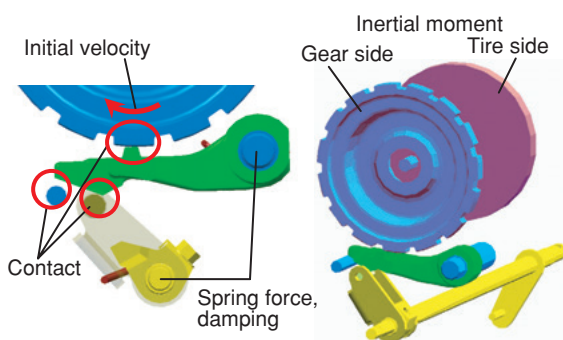


Fig. 12 Simulation model

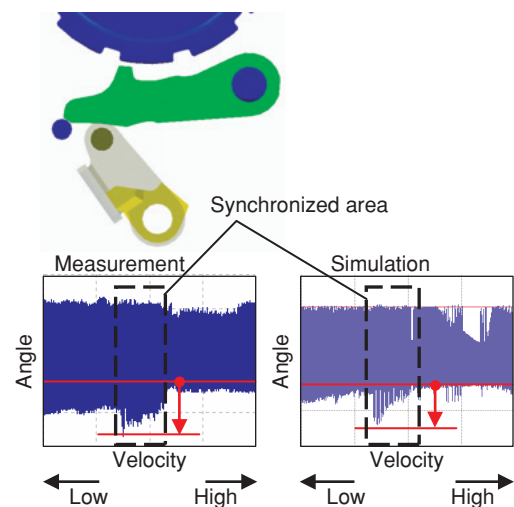


Fig. 13 Comparison between measurement and simulation

4.3. Verification of Prediction Accuracy

As an example, Fig. 13 shows the results of the measured results and the predicted results of the degree of pawl engagement versus vehicle speed. The figure in the frame of bold line shows synchronized area. The predicted engagement of the pawl with the gear and the synchronized velocity correlate well with the measured values.

5. Conclusion

The rotational behavior in the parking lock device of an automobile automatic transmission was made measurable. Based on this, the mechanism of occurrence of parking lock was reproduced and a prediction method was constructed.

The main points concerning this prediction method are as follows.

- (1) It was possible to measure the rotational behavior of the parking lock device using gap sensors in the case where the lever is put in the P position while the vehicle is in motion.
- (2) From the measurement results, it was possible to reproduce the mechanism where parking lock occurs. A high degree of engagement occurs in a vehicle moving at high speed when the cycle of the tooth space of the gear is synchronized with the cycle at which the pawl and lever are repelled by the gear and return.
- (3) A method of predicting parking lock in a moving vehicle was constructed by multibody dynamics analysis and the prediction accuracy was increased by using the damping coefficient of the brake spring obtained from the measurement data.

As a result of the above, it was possible to determine the specifications of the parking device that could help prevent the occurrence of parking lock in a moving vehicle while taking account of the various restrictions on installation.

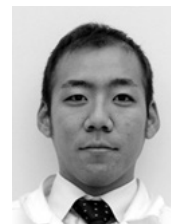
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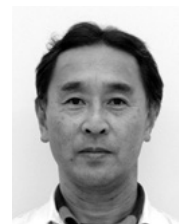
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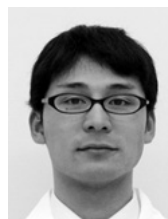
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