

Operating Force Simulation for Automatic Transmission Select Lever

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ABSTRACT

A highly accurate method was developed for simulating the operating force for the select lever of an automobile automatic transmission by considering the internal link mechanism, the contact between parts, the load loss in the wire, and other factors. In order to improve accuracy, an experimental formula was introduced that takes the spring coil angle as a parameter to simulate the hysteresis characteristics of the twisted coil spring that is an essential factor in the mechanism. A method was also created to use mechanical system analysis tools in order to reduce the labor involved in simulation. The use of these means made it possible to simulate the operating force characteristic curve with an accuracy diverging by no more than 5% from measurement values, with half the labor previously required, and with consideration for the main factors influencing the characteristics. As a result, it has become possible to verify issues including excessive operating force and intermediate stopping at the specification study stage.

1. Introduction

In recent years, it has become necessary to reduce the operating force for the select lever used to select the position on an automatic transmission of an automobile, in order to improve the product merchantability. At the same time, it is necessary to set the operating force to a somewhat high value in order to prevent intermediate stopping, a phenomenon whereby the select lever stops in an intermediate position outside one of the correct positions such as P, R, N or D. It is also necessary to appropriately set not only the maximum value of the operating force, but also the way in which the operating force rises along with the lever stroke between one position and another, because these factors affect the overall shift feeling.

A very large number of study hours and test man-hours were required for development to ensure that both the merchantability and function of the select lever were satisfactory. For this reason, it was necessary to simulate the operating force of the select lever as a characteristic curve of lever stroke versus force, at an accuracy that enabled the variations in specifications to be judged. However, although

there is a reported example of simulation technology related to the operating force of the shift lever for a manual gearbox⁽¹⁾, there are no reports related to simulation technology concerning the operating force of the select lever for an automatic transmission, which has an entirely different mechanism.

This paper describes the development of a method to simulate the operating force of the select lever for an automatic transmission.

2. Mechanism and Characteristics

2.1. Description of Mechanism

Figure 1 shows the position select lever of an automatic transmission. The position selector consists of the select lever on the driver's seat side, a control shaft on the transmission side, and a wire that connects these two parts together. As a result of the lever's operation, the control shaft rotates via the wire. The selection of the hydraulic control system related to each position is made by a manual valve linked to the control shaft. On this control shaft are positioning detents and a

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mechanism that locks the driveline when the select lever is in the parking position (hereafter called the “P position”).

Figure 2 shows this mechanical locking device. The parking brake lever, which operates the parking pawl, is pushed against the control shaft by a torsion coil spring. As a result, when the vehicle is parked, the lever can be shifted to the P position regardless of the parking gear phase. Also, if the lever is inadvertently moved to the P position while the vehicle is running, the parking gear will flip out the parking pawl, preventing the driveline from locking.

2.2. Operating Force Characteristics of the Select Lever

Figure 3 shows the relationship between the select lever stroke and the operating force, which is the object of the simulation. These force characteristics are determined by the force due to the detent, the mechanical lock mechanism, the force loss due to the wire, the link on the selector lever side, displacement due to looseness and bending of the wire, and the large amount of hysteresis.

Figure 4 shows an explanation of this characteristic curve. During the first half of the lever operation, the operating force is generated in response to the reaction force, and during the latter half a holding force is generated in response to the suction force that prevents the lever from stopping outside the correct position. The directions of these forces reverse when the lever is moved in the opposite

operating direction.

The two characteristics between P and R are determined by the operating condition of the mechanical lock mechanism. When the vehicle is parked and the lever is shifted to the P position, the lever will go into either a locked state in which the pawl engages with the parking gear, or an unlocked state in which it is sitting on the gear, depending upon the phase of the parking gear with respect to the parking pawl, as shown in Fig. 5. If the pawl is sitting on the gear, the parking brake lever spring force is added to the operating force. Consequently, the operating force characteristics between P and R differ depending upon whether the pawl is engaged with the gear or is sitting on it.

The main issues during development are the magnitude of the operating force and the existence of suction force which affect the transmission's merchantability and function. The force near the P position is high due to the mechanical lock mechanism, so the following two items are particularly important. Figure 6 indicates this on the characteristic curves.

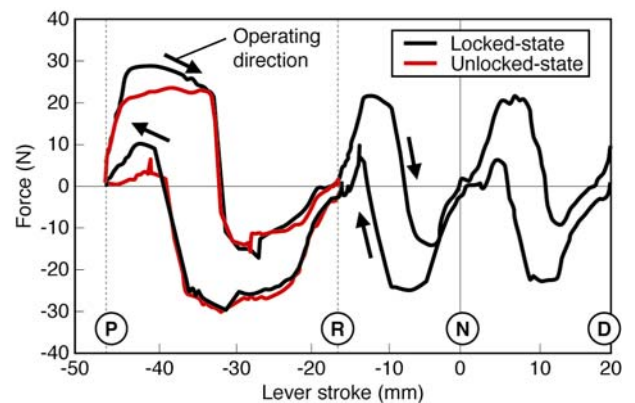


Fig. 3 Operating force characteristic

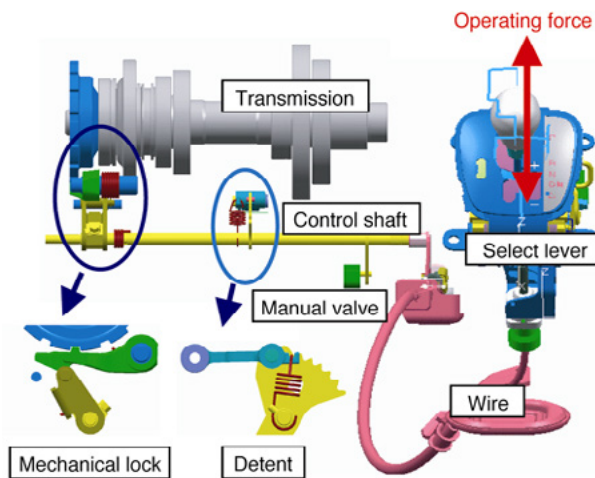


Fig. 1 Position selector

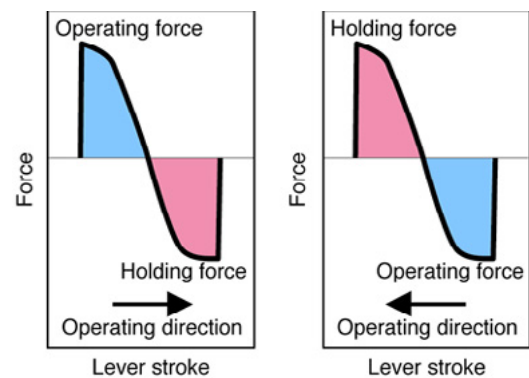


Fig. 4 Explanation of characteristic curve

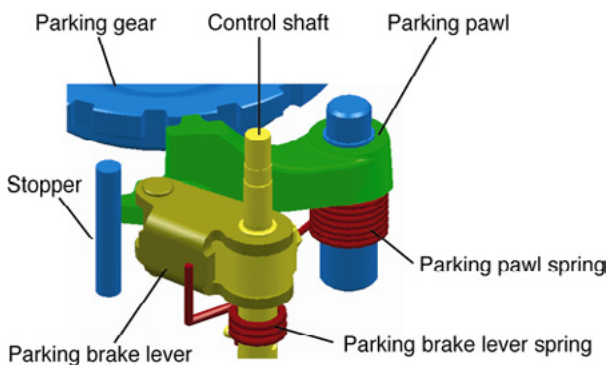


Fig. 2 Components of mechanical locking device

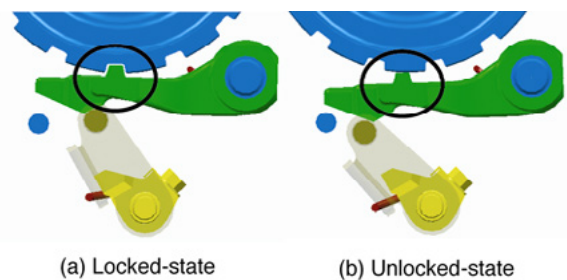


Fig. 5 Position of parking pawl and parking gear

- (1) The magnitude of the maximum operating force going from P to R when the pawl is engaged with the gear, from the viewpoint of reduction of the operating force
- (2) The existence of a suction force due to shifting of the lever from R to P when the pawl is sitting on the gear, from the viewpoint of preventing intermediate stopping.

Intermediate stopping occurs when the suction force generated at the detent is offset by the force generated by friction and other factors.

If the detent force is reduced in order to reduce the maximum operating force, the suction force will also be reduced, increasing the chances that intermediate stopping will occur. In other words, (1) and (2) are in conflict with each other. In order to both realize a reduction of the maximum operating force and prevent the occurrence of intermediate stopping at the specification study stage, it is necessary to simulate the operating force characteristics.

3. Simulation Method

3.1. Conventional Simulation Method

The conventional method of simulating the operating force was implemented by checking the joint angle of linkage and the contact angle of the contact part by making a plot for each layout, performing a mathematical calculation of the force transfer efficiency and contact force, and totalizing the calculation results for each element.

However, since there are multiple link mechanisms and force elements, a large number of man-hours are required to perform the simulation. A point calculation was performed at each position and also at several points between P and R. In addition, the simulation accuracy was low, so it was not possible to make a quantitative judgment from the predicted value. Furthermore, the simulation of displacement in the operating direction necessitates simulation of the balance between forces generated at each point in consideration of bending, so it was impossible in practice.

Thus, the issues of simulation accuracy and simulation man-hours were attendant to the conventional method.

3.2. Raising the Accuracy and Reducing the Simulation Man-hours

In light of the above, in this development the following methods were used in order to raise the simulation accuracy

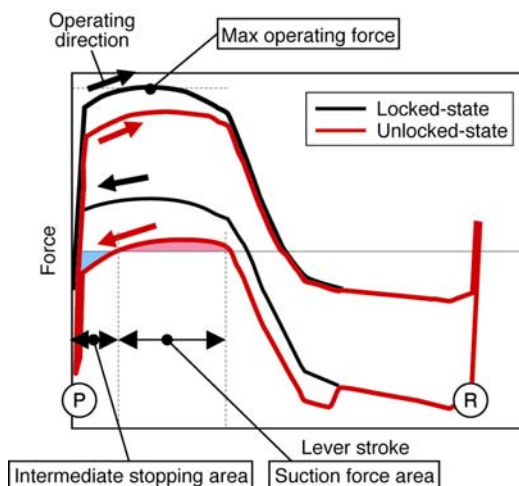


Fig. 6 Max operating force and intermediate stopping

while reducing the necessary number of man-hours for simulating the operating force characteristics of the lever.

- (1) Construction of a method of accurately simulating the component element characteristics in order to raise the simulation accuracy
- (2) Simulation of a characteristic curve using a mechanical analysis tool in order to reduce the number of man-hours required.

Details of each of these items are described below.

3.2.1. Raising the accuracy of simulating the hysteresis characteristics

As a result of investigating the component elements that affect the accuracy of the simulation, it was found that there was a large difference in the theoretical force and the actual force generated inside the transmission. Figure 7 shows the operating torque characteristics versus angle of rotation of the control shaft, together with the theoretical values. These characteristics are formed by the force of the detent and the mechanical lock mechanism. The difference between the actual value and the theoretical value is large when the parking pawl is sitting on the parking gear near the P position. Accordingly, attention was paid to the characteristics of the parking brake spring whose characteristics affect only the force characteristics in this vicinity.

As a result of measurement, it was found that the characteristics of the parking brake spring had a large amount of hysteresis. These characteristics are dependent on whether or not the spring turns are touching each other, whether or not the end face of the spring touches the other, and whether or not the spring is tilted. It was found that by using the hysteresis characteristics obtained from measurement in the calculation, the accuracy of the simulated lever force characteristics rose and also the necessary accuracy for quantitatively judging the force was obtained. Accordingly, an attempt was made to predict the hysteresis characteristics.

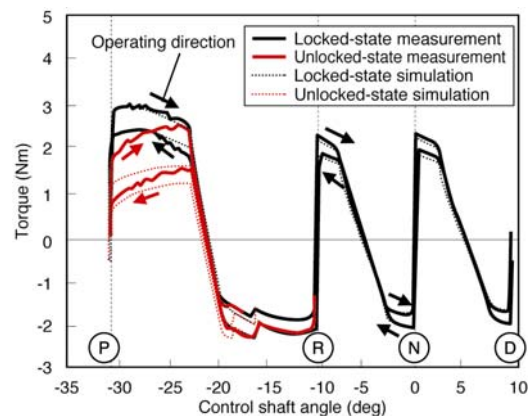


Fig. 7 Operating torque characteristic in transmission

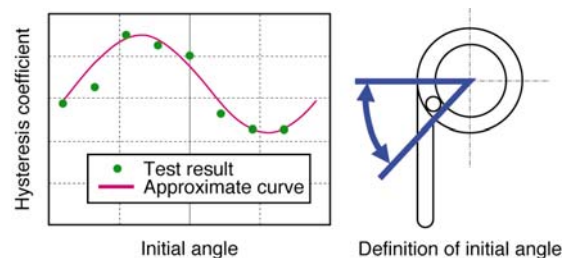


Fig. 8 Result of spring test

In order to investigate the relationship between the hysteresis characteristics and the spring specifications, the state of mutual contact between the turns and the number of turns of the parking brake lever spring were changed, and the characteristics obtained were measured. The hysteresis width is affected by the absolute value of the torque, so the hysteresis width at certain measurement points was divided by the mean value of the torque and arranged as a non-dimensional coefficient. As a result, it was found that there was a constant degree of correlation between this non-dimensional coefficient and the initial phase angle, which is the turn angle between the spring arms shown in Fig. 8. An empirical equation for predicting the hysteresis characteristics was derived using the initial phase angle as a parameter.

In order to verify the appropriateness of this empirical equation, tests were carried out using parking brake lever springs of various specifications. Figure 9 shows an example of a comparison between the measured value of the characteristics, the theoretical value using the conventional calculation formula, and the theoretical value obtained by means of the derived empirical equation. From the above verifications, it was confirmed that the accuracy of simulating the spring hysteresis characteristics rose using the empirical equation.

3.2.2. Reduction of simulation man-hours

Figure 10 shows the elements that are taken into account in this simulation. The selection of each element takes into account the effect on the force characteristics.

There were apprehensions that if the number of

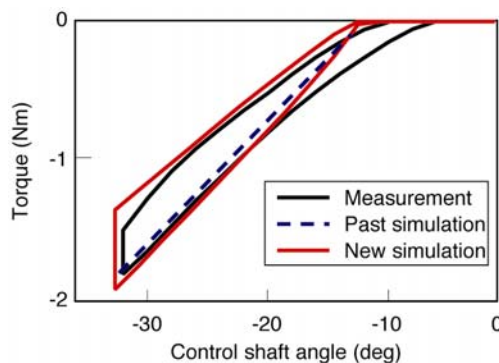


Fig. 9 Parking brake spring characteristic

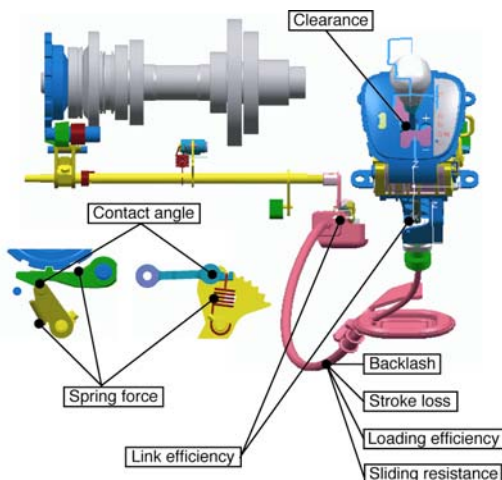


Fig. 10 Factors in select lever operating force

calculation points were increased in order to take account of these elements and obtain the force characteristics as a characteristics curve, the number of simulation man-hours would increase. For this reason, a simulation was performed by mechanical analysis, using a 3-dimensional CAD layout of the vicinity of the select lever. Previously performed manual calculation was eliminated in order to minimize the increase in man-hours. Also, it was possible to simulate not only the force but also the displacement. A description of a simulation method constructed using a mechanical analysis tool is given below.

(1) Force transfer efficiency The force transfer efficiency changes according to the joint angle of the wire and the position of the link. Previously, the force transfer efficiency for each lever stroke was obtained by plotting a diagram and performing manual calculation. Also, in the case of a link mechanism that had a complicated 3-dimensional layout, there was a risk of an error occurring during the manual calculation process.

In this development, rotational and translational constraint characteristics were made directly from the 3-dimensional layout of the link mechanism, and the force transfer efficiency was automatically calculated.

(2) Contact angle The reaction force to the control shaft changes according to the contact angle between the detent and the detent arm roller, and between the parking pawl and the brake lever roller. Previously, the contact angle of the detent and the parking pawl for each rotational angle of the control shaft was obtained using a calculation formula or by plotting a diagram.

In this development, the contact angle was automatically calculated by means of a constraint definition. The force due to friction of the contact part was also taken into account. However, contact elements should be used in order to define the relationship between the detent and the roller and between the parking pawl and the brake lever in accordance with the actual situation. This requires much calculation time and the analysis becomes unstable. For this reason, it was assumed that for normal operation, the contact between each part was maintained, and point and curve constraint parameters were used on the track of the roller's center.

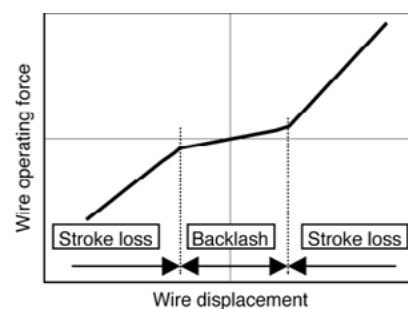


Fig. 11 Non-linear spring for wire displacement

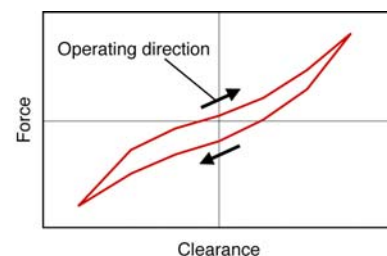


Fig. 12 Non-linear spring for lever stiffness and clearance

(3) **Wire characteristics** The wire characteristics consist of four elements: force efficiency, sliding resistance which affects force, and backlash and stroke loss which affect displacement. Force efficiency was reproduced by calculating the friction of the rotating shaft for the link on the select lever side in order to generate force loss. The displacement elements of backlash and stroke loss, which could not previously be taken into account, were calculated by dividing the wire into two parts in the model, and connecting the two parts by means of a non-linear spring that exhibited a non-linear displacement to the force shown in Fig. 11.

(4) **Select lever characteristics** The looseness and stiffness of the select lever affects the displacement. A non-linear spring that had the hysteresis is shown in Fig. 12.

(5) **Spring force** Load characteristics that vary according to the operating direction were modeled in order to take into account the force of the parking brake lever spring including the hysteresis characteristics obtained in 3.2.1. Also, a non-linear spring that regulated the direction of rotation was modeled in order to reproduce the state in which the parking brake lever is pushed against the control shaft.

(6) **Supporting method** A method of supporting the creation of a model was constructed in order to permit the designer to readily use this operating force simulation method. Before performing analysis, the designer creates basic constraint parameters in a 3-dimensional CAD layout and a parameter file to which various specifications have been input for the analysis. When the parameter file is executed, the simulation will take place automatically and the results are output as a graph.

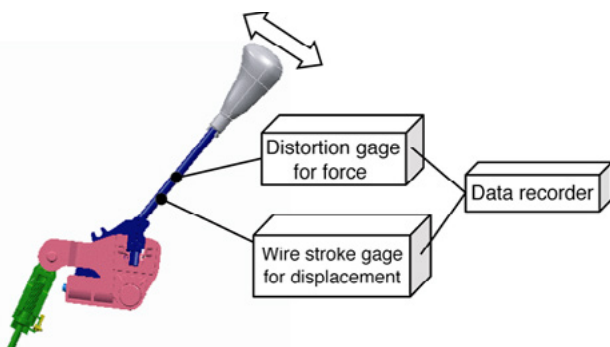


Fig. 13 Operating force test apparatus

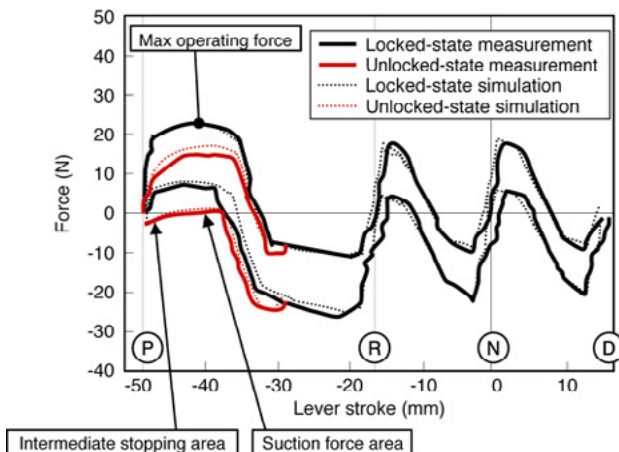


Fig. 14 Comparison of test result and simulation

As a result of performing the above, it became possible to characterize the shift force as a curve, in contrast to the conventional method, which was a method of simulation based on points. Factors that could not previously be taken into account were added. A supporting method was employed, enabling the number of simulation man-hours to be cut in half.

4. Verifying the Accuracy of the Simulation

In order to make a detailed comparison of the measured values and the theoretical values over the entire stroke, the select lever operating force and the operating stroke were measured using the distortion gauge and wire stroke gauge shown in Fig. 13. The resulting data was acquired digitally.

Figure 14 shows a comparison of the measured values and the theoretical values obtained using this method. The existence of intermediate stopping when the pawl was sitting on the gear and the maximum operating force when the pawl was engaged with the gear were simulated accurately. Also, the force and displacement were accurately predicted to within $\pm 5\%$ over the entire stroke.

5. Conclusion

A method of accurately simulating the operating force characteristics of the shift lever of an automatic transmission to within $\pm 5\%$ was developed. The constructed technology is summarized below.

- (1) It was possible to simulate the hysteresis characteristics of the torsion coil spring, which greatly affect the select lever operating force characteristics, by means of an empirical equation.
- (2) It was possible to simulate the force characteristic curve while taking into account the main factors that affect the operating force characteristics of the select lever, using one half of the previous number of man-hours.

By adopting this method, it became possible to verify the occurrence of excessive operating load and intermediate stopping at the specification study stage.

Reference

- (1) Ichikawa, N.: Shift Feeling Evaluation of Farm Tractor by Mechanical Dynamic Analysis, KUBOTA TECHNICAL REPORT, No. 31, p. 87-92 (1996)

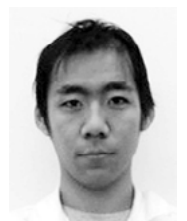
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