Simulation on Synchronization Mechanism of Transmission Gearbox

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Abstract

A simulation technique has been developed for describing the synchronization mechanism of a transmission gearbox installed in a heavy-duty truck. For shifting up from the second gear to the third gear, the movement and contact force of the synchronizer components are simulated with an analytical model using ADAMS. The movement of the synchronizer can also be visualized with an animation technique. Causes of abnormal phenomena while shifting up, such as abnormal shift reaction force and gear squeak, have been hard to analyze with a conventional experimental approach, but this simulation enables us to understand the synchronization mechanism and gives useful information how to improve the transmission shift feeling. Furthermore, this technique is an effective design tool to study the effects of parameters, such as shifting speed, friction coefficient at the contact point, and chamfer shape of the spline.

1. Introduction

The market needs for vehicle controllability and operational comfort tend to become higher. The transmission shift feeling is one of important elements influencing the evaluation of vehicle controllability and operational comfort. Abnormal shift reaction force and gear squeak worsen the transmission shift feeling.

These phenomena are essential facts for the evaluation at the development stage of the transmission. As the duration of these phenomena is very short and the gear-shifting mechanism is complex, it is impossible to figure out the mechanism of these phenomena through experimental approaches. Therefore, a lot of time was necessary for reaching an acceptable level of transmission shift feeling.

In this research, the technique are developed using ADAMS to simulate the synchronization mechanism of transmission gearbox and to explain the cause of an abnormal shift reaction force and gear squeak. We created a model for describing the complex synchronization mechanism and predicted the movement and contact force of the synchronizer components for a short time phenomenon. The movement of the synchronizer components can also be visualized with an animation technique. This simulation gives us the knowledge on the abnormal shift reaction force and the gear squeak. This paper deals with the simulation technique and its results.

2. Objective system

The object of the simulation is a transmission gearbox installed in a heavy-duty truck. The movement of the synchronizer system components of third gears is simulated.

This system takes the double synchronization mechanism and consists of the following eight components. (Figs. 1 and 2)

(1) Clutch gear (one with three gears)
(2) Synchronized cone
(3) Inner ring
(4) Outer ring

(5) Hub
(6) Sleeve
(7) Plunger
(8) Detent

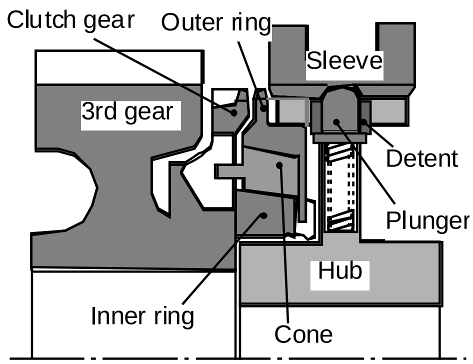


Fig.1 Simulation object

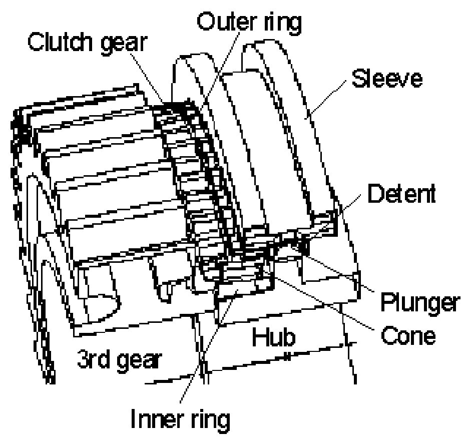


Fig.2 Solid model for animation

We analyzed the process of shifting gears from the second gear to the third gear.

The shifting up process consists of the following 6 events (Fig. 3):

(1) Movement of the sleeve
(2) Detent (The sleeve slides over the plunger)
(3) Index (Maintain the position of the hub and the outer ring)
(4) Balk (The rotation synchronization of the hub and the clutch gear)
(5) Mesh of the sleeve and the outer ring
(6) Mesh of the sleeve and the clutch gear

To ensure a high accuracy of the simulation, it is important to precisely simulate each event. Hence, the simulation results of each event were logically checked and then a whole simulation model was made.

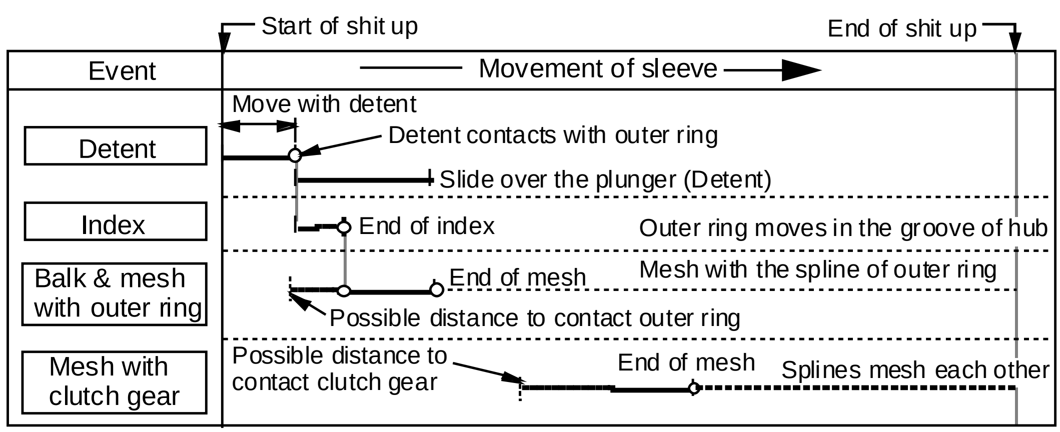


Fig.3 Event flow

3. Simulation model

3.1 ADAMS Model

The position of transmission system components and the contact reaction force were defined with ADAMS force functions (Fig. 4). These force functions

(1) decide if there is any contact when the initial clearance exists among the components.

(2) indicate the friction force when the components contact each other.

(3) decide if the spline has a mesh with the sleeve, outer ring or clutch gear.

To judge the contact, the impact function of ADAMS is used and to define the contact friction force, the step function is used.(Fig. 5)

To define the mesh of the sleeve and the spline of the outer ring, the meshing process is divided into two steps (Fig. 6), we developed a FORTRAN subroutine program which calculates the contact force in judging the contact at the chamfer and inserted it into the ADAMS.

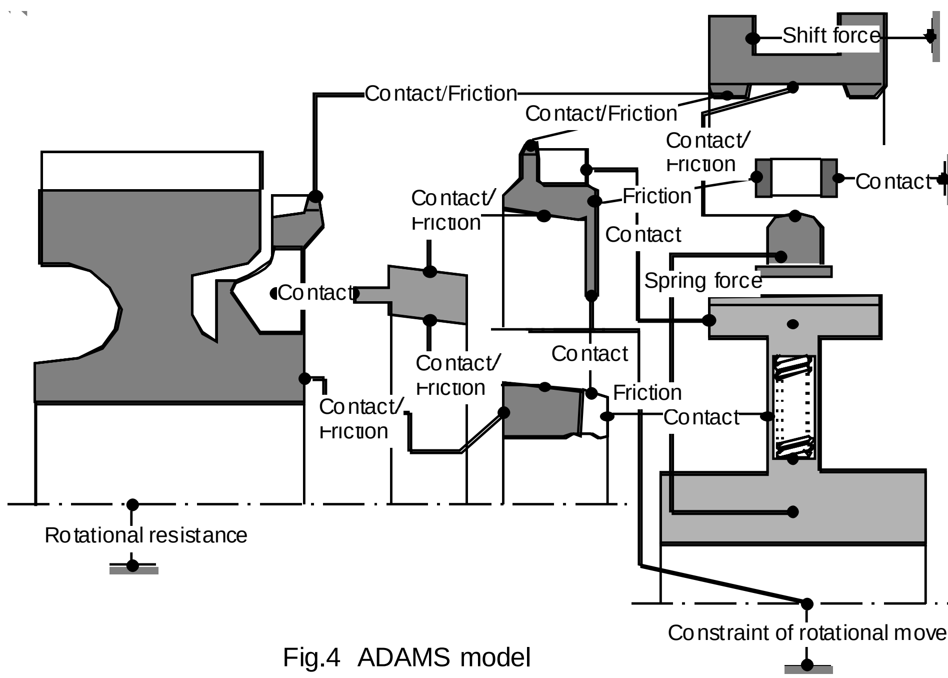


Fig.4 ADAMS model

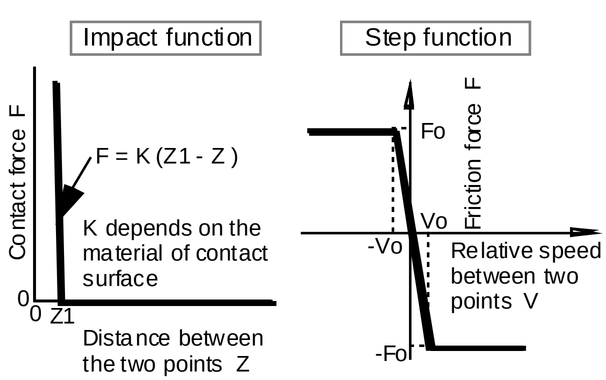


Fig.5 Impact function & step function

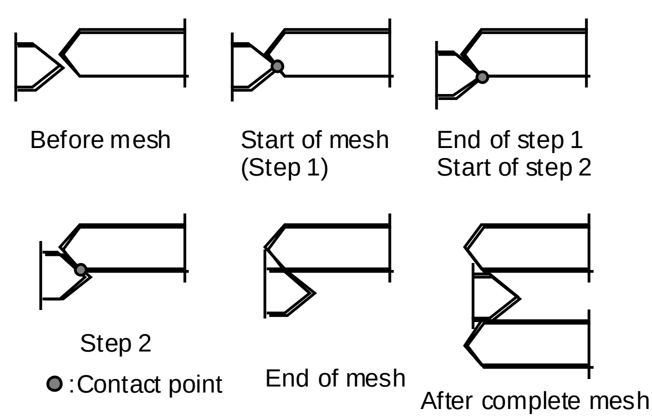


Fig.6 The process of sleeve meshing

3.2 Simulation Conditions

In focusing an abnormal shift reaction force occurred while meshing of the sleeve and the clutch gear after the synchronization we conducted the simulation. The simulation conditions are as follows:

(1) The initial rotational speed:

The hub is fixed. The initial rotation speed of 2886 deg/sec was given to the clutch gear relative to the hub.

(2) Maximum Shift Force: 3 kN at the sleeve

(3) Shift Speed:

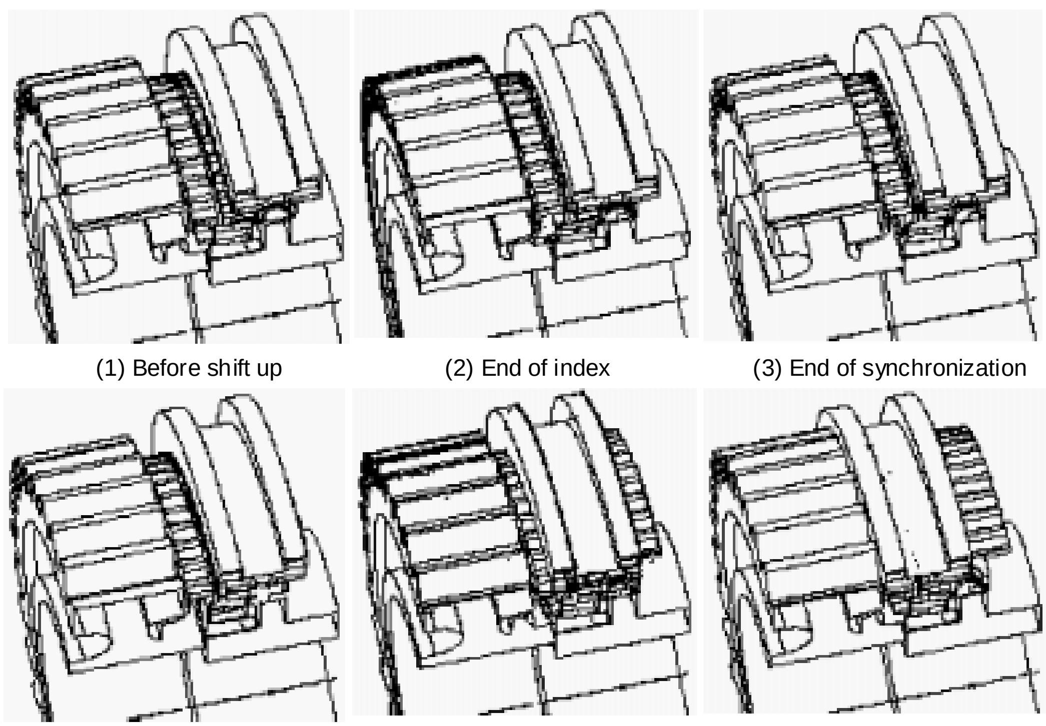
15mm/sec (except during the rotational synchronization)

(4) The rotational resistance torque of driven gear:

27.29 kN mm is given to the clutch gear.

4. Results of Simulation

The duration for the simulation was set as 0.4 second. with an calculation time interval of 0.002 second. The time history results were given to the solid model for the animation (Fig. 2) to visualized the movement of the components (Fig. 7).



(1) Before shift up (2) End of index (3) End of synchronization

(4) End of mesh with outer ring (5) End of mesh with clutch gear (6) End of shift up

Fig.7 Animation

According to the calculated results, the logical validity was studied about the movement of each component and the contact force between components.

(1) The movement of the sleeve and the reaction force (Figs. 8 and 9)

(a) The sleeve moves at 150mm/sec until the hub and the clutch begin to synchronize and stops. After the end of this synchronization process, the sleeve moves to contact with the clutch gear in repeating backward and forward movements and meshes finally with the gear spline.

(b) Before the synchronization, the reaction force of the sleeve is equivalent to the detent force. During the synchronization, the reaction force becomes the maximum operational force of 3 kN.

(2) The detent force (Fig. 10)

(a) The contact force, which occurs when the sleeve slides over the plunger, depends on the shapes of the sleeve and plunger. When the tangential line of the plunger filet has the same shape as the sleeve, the contact force becomes maximum.

(3) The rotational speed of the clutch gear (Fig. 11)

(a) When the hub and clutch start to synchronize, the rotational speed decreases. Just after the synchronization, the index is released, the clutch gear rotates to the opposite direction.

(4) The relative displacement of the clutch gear and sleeve (Fig. 12)

(a) The sleeve and clutch gear contact at A in Fig. 12. They contact at B again after sliding over the chamfer for the reason (3). As the relative speed of gear and sleeve becomes zero at the point of C, the splines mesh each other.

(b) The reverse movement of (1) is the phenomenon related to the relative position of the clutch gear and sleeve and the difference of rotational speed. This reverse movement is supposed to be the reason for the abnormal shift reaction.

As these phenomena are not contradictory to our knowledge, we conclude that this simulation model is effective to simulate the transmission system behavior.

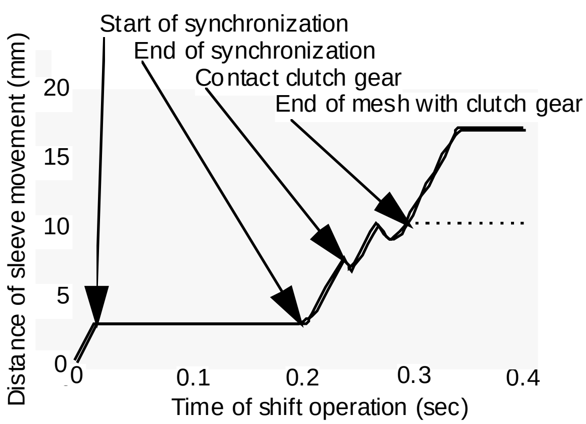


Fig.8 Distance of sleeve movement

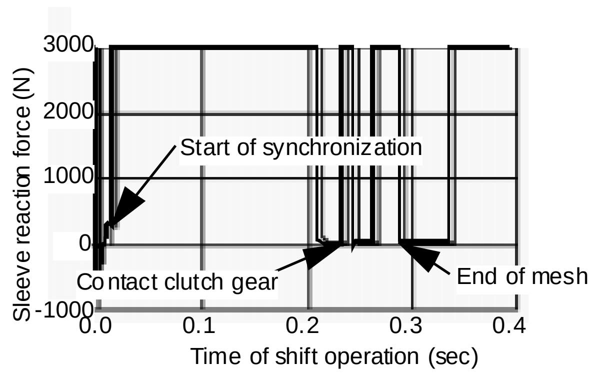


Fig.9 Sleeve reaction force

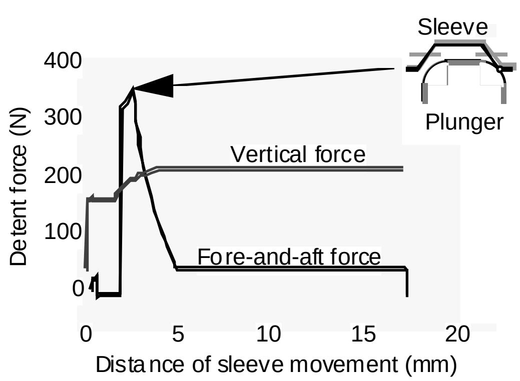


Fig.10 Detent force

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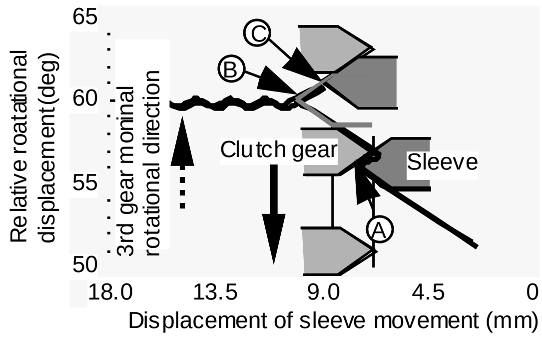

Fig.12 Relative rotational displacement between sleeve and clutch gear

5. Parameter Study

As the validation of the simulation model had been confirmed, the influence of some parameters on the operational shift feeling was studied. The influences of the shifting speed and friction coefficients are presented.

5.1 The influence of the shifting speed

The simulation was performed at the shifting speed of 275mm/sec and 392mm/sec and compared to the simulation at the shifting speed of 150mm/sec.(Fig. 13) With the shifting speed change, the two-stage reactions of the sleeve and clutch gear were changed. This was caused by the relative reverse rotation of the clutch at the index release. This phenomenon depends on the power balance between the reverse rotation force of the gear and the synchronization force of the sleeve, and the first contact point of the gear and sleeve.

For example, in the case of 150mm/sec shifting speed, the synchronization force of the sleeve is smaller than the reverse rotational force of the clutch gear. Until both forces become equal, the gear rotates in the opposite direction. At the same time the sleeve goes forward and backward on the chamfer. On the other hand, when the shifting speed is 275mm/sec, the synchronization force of the sleeve and the reverse rotation force of the gear are almost equal and the first contact point of the sleeve and the gear is not by chance influenced by the reverse rotation force of the gear. The sleeve and the gear mesh smoothly without a backward movement.

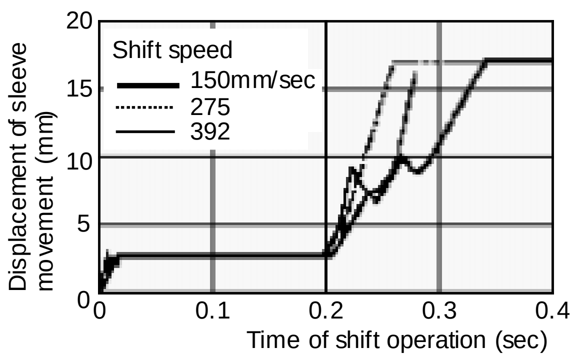

Fig.13 Variation of shift speed

5.2 The influence of the friction coefficients

The simulation was performed under the condition of the friction coefficient of zero between the side of the inner ring and clutch gear (Fig. 14). As a result, the time spent for the synchronization between the hub and clutch gear was longer. This parameter is significant.

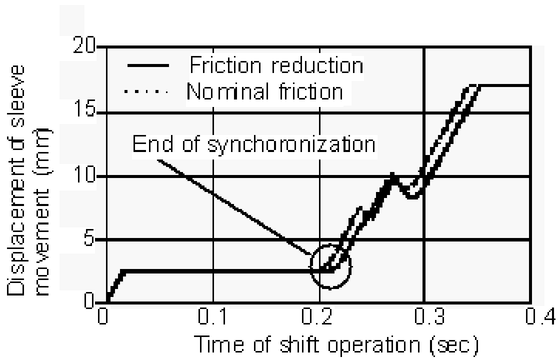

Fig.14 Variation of friction coefficient

6. Summary

The gear shifting process which is impossible to measure by an experimental approach could be simulated with ADAMS virtual prototyping software and the following results were found:

(1) The ADAMS model for accurately simulating all gear shifting mechanisms was created

(2) By applying the calculated results to the solid model, the movement of the transmission system components is visualized.

(3) The power difference between the synchronization force of the sleeve and the reverse rotation force of the gear is one of the reasons for the abnormal shift reaction.

(4) As this simulation technique can be used to predict the effect of the friction coefficient of the contact point and the shape of the chamfer, this is efficient as design tool.

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