

Development of a Slip Speed Control System for a Lockup Clutch (Part III)

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ABSTRACT

It is difficult for a conventional robust control algorithm to assure the performance of a slip speed control system, because the plant (lockup system) includes the nonlinear characteristics of the hydraulic system and large changes in the parameters of the slip model at low vehicle speed. The purpose of this study is to reduce the fuel consumption and improve the drivability of vehicles at takeoff by using a slip speed control system.

Providing a large feedback gain is effective in reducing the influence of nonlinearity. However, since the operating parameters of the lockup clutch change depending on the driving conditions, that is not possible. A feedback compensator with a gain-scheduled H_∞ control method was used in this study to solve these problems. The effectiveness of the slip speed control system was demonstrated in driving tests. Using this control system, the slip speed can be controlled with high accuracy, thereby reducing unnecessary revving of the engine. The system is expected to contribute to improved fuel economy.

1. INTRODUCTION

As environmental problems such as global warming have become more serious, improving the fuel economy of automobiles has become an important issue. With the spread of automatic transmissions, efforts have been made to develop slip lockup control technology as a measure for improving the fuel efficiency of torque converters. In part one⁽¹⁾ of this report, the authors explained how the lockup clutch in the torque converter is engaged from lower vehicle speeds on the drive side.

In part two,⁽²⁾ the authors presented fine slip speed control technology for expanding the fuel-cutoff range during coasting and demonstrated the effect on increasing fuel efficiency.

Figure 1 shows the results of applying the drive-side slip speed control system reported in part one to a vehicle. Slip speed control begins after first increasing the pressure of the lockup differential pressure at a specified rate using open loop control up to a predetermined slip rate. Although the characteristics of the torque converter as shown in Fig. 2 are linear in the region where the ratio of the input speed (impeller) to the output speed (turbine) is large, the characteristics are nonlinear in the remaining regions in which the speed ratio is small. This linear region is modeled and slip speed control is applied to the region. In the nonlinear regions, degradation of control performance due to accumulation of errors in the control unit is prevented by using open loop control. This reduces the amount of engine revving compared with conventional lockup control and improves fuel efficiency. However, in the open loop control region, because the slip speed cannot be accurately controlled, it is difficult to reduce engine revving further.

The aim of this study is to engage slip speed control from the low speed ratio region directly after takeoff in order to prevent unnecessary engine revving and further improve fuel economy. The engine speed response in the region to the transition to slip speed control depends strongly on the hydrodynamic characteristics of the torque converter, requiring changes to mechanical components in order to change the engine speed response.

This control technology makes it possible to control electronically the response of the engine speed immediately after takeoff and is expected to simplify mechanical tuning. A large torque multiplication effect cannot be obtained with a small throttle opening. Accordingly, for good drivability, it is important to improve the throttle response by reducing the dead time of the torque converter.

In designing this slip speed control system, we investigated how to model the plant in the low speed ratio region immediately after takeoff. The results confirmed that the plant can be modeled by adding a simple correction to a low-order LPV (Linear Parameter Varying) system, the same is in the previous papers.

The differential pressure valve used in this study has a problem of extremely poor responsiveness in the low pressure range that is controlled at extremely low speeds. In the extremely low speed range, the gain of the plant is large, and the nonlinear characteristics of the oil pressure valve have a large effect on control performance. Although making the feedback gain large is effective for resolving these problems, in the μ -synthesis controller described in the previous papers, the large variation in the parameters considered made it difficult to derive a feedback controller to compensate for the worsened performance in the low speed range. A feedback compensator was therefore designed using the gain-scheduled H_∞ control method, by focusing on the high correlation between the directly measurable turbine speed and variations in the slip control system parameters, and taking the turbine speed as a scheduled parameter.

This paper describes the design method of the slip speed control system, and presents both the computer simulation results and the vehicle experiment results. These results indicate that the slip speed control system provides good control performance.

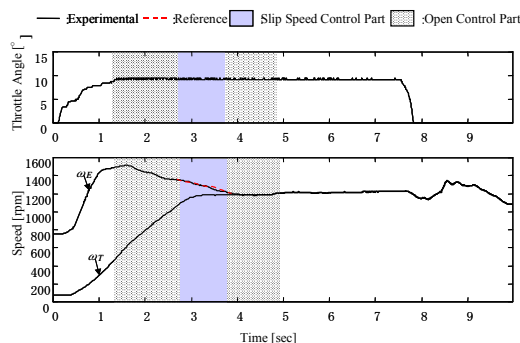


Fig. 1 Results obtained with drive-side slip speed control system

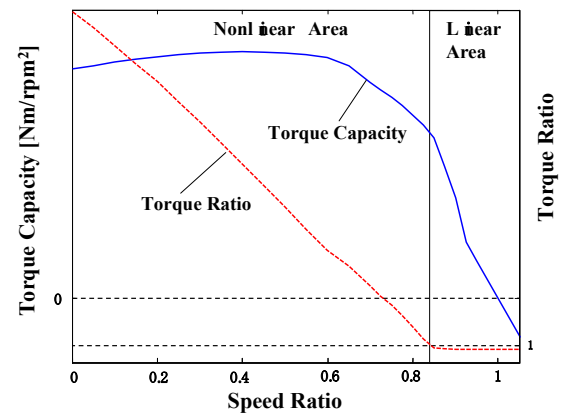


Fig. 2 Characteristics of torque converter

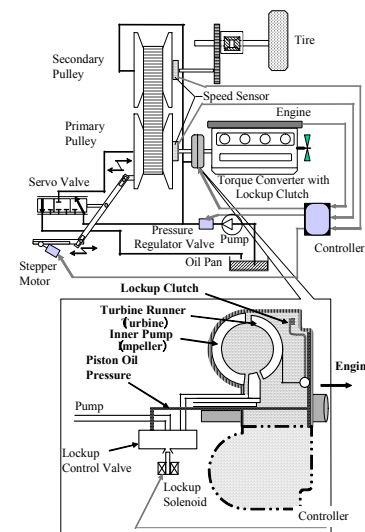


Fig. 3 Torque converter with lockup clutch

2. SYSTEM FEATURES

Figure 3 shows a schematic diagram of a torque converter with a lockup mechanism. A lockup clutch is positioned between the impeller pump and the turbine runner. The clutch is driven by the differential pressure between the applied pressure and released pressure (i.e., lockup differential pressure). This differential pressure is adjusted using a control valve, and the slip rate between the impeller speed and turbine speed can be controlled by the lockup clutch.

3. CONTROL SYSTEM DESIGN

3.1. Plant Modeling

Basic experiments were conducted under each set of conditions as the control range was extended to low speed ratios. The results showed that the slip speed control system can be expressed according to Eq. (1) as an LPV system where the coefficient of viscosity C_{SLP} is determined by the speed ratio τ as well as the conventional turbine speed ω_T .