CHAPTER 5
CONTROL OPTIMIZATION AND SYSTEM SIMULATION

General control turning methods, such as Z-N method, are used for general purpose and perform with general performance. Some range of instability or error is permitted for such turning methods, since they are “general” methods. For specific cases or specific requirements, optimization must be exercised to reach the control demands.

Since the clutch actuator requires rapid motion within short distance, and only small setpoint tracking error is allowed. The control parameters obtained from Z-N turning method is not sufficient for the system requirement, as shown in Figure 4.3-7. Implementation of optimization aimed at the control stability is definitely required, which is executed in this chapter.

Beside optimization of the control parameters, results of the simulation with regard to the optimized systems, including both cultch controller, clutch actuator, and the whole powertrain, are presented in the last section.

5.1 Optimization Algorithm

For the last 50 years, several methods for determining the PID controller parameters have been developed. Some of them deal with some kinds of optimal approach. Actually, the development of PID optimum turning rules has been one of the major areas of research about the PID controller. From the original works of Ziegler and Nichols (Z-N) and Cohen and Coon, a great number of methods have been proposed, some of them giving approach to obtain the PID optimal gains. Macgregor, Wright & Hong (1975) for example, suggested a method to obtain the optimal gains from plots of contour variances under PID feedback control. The resulting controller can be seen as a linear-quadratic-Gaussian (LQG) type. The

PID design based on the Optimal Linear Quadratic theory was also discussed by Argelaget (1995). On the other hand, Vu (1992) gives an iterative algorithm that arises from a Riccati-like equation to obtain the PID parameters that minimize the output variance of the closed-loop system [31]. Also some other general optimum methods are practically used. The method by Haalman is designed for system having dead time; the methods Modulus Optimum (BO) and Symmetrical Optimum (SO) apply to systems without dead time. However, such methods always take controlled system as a simplified process such as second-order system or third-order system.

The target of this study in this chapter is to optimize the PID control parameters with a complete model which much close to the reality. Such propose is expected to have a better result then deal with a simplified model, because the complete model provides more details of system dynamic characters to the optimization. For example, some discrete-like characters, i.e. static-dynamic friction, is rarely be shown in a simplified model.

As the optimization of mechanical parts in CHAPTER 3, the control optimization is implemented in the interface the same with the dynamic model to give more efficient computation.

For the above proposes, the optimum control turning is set to be an optimization problem where the cost function is to minimum the control error between set point and feedback signal, where the dynamic model has been programmed in CHAPTER 2. In the optimization problem, the controlled system is the complete model of clutch/clutch actuator system. And the implementation uses optimization toolbox within Matlab®. The detail definition of the optimization problem is in the next section.

Local minima are the most challenge for optimization. In general, the control cost function may have many local minima. Since no algorithm can guarantee to obtain a global minimum, efforts should still be exercised to obtain a better solution. Genetic Algorithm (GA) is thought to be a more possible method to find the global minimum in this day. However, since the design variables, the control parameters, have wide ranges for variations in the control function, GA may be very inefficient in computation to be used. To deal with such problem, in this study, better initial variables are tried to obtain to provide an initial point which more closes to the minimum point suitable for the control requirement, and then using SQP method with different minimum step size of direction searching to find the minimum point which feasible for the system requirement and to avoid local minima which may give an unsuitable solution to the optimization. Such initial variables, which may close to the global minimum, are determined by traditional PID turning method, as discussed in section 4.3 .

5.2 PID Control Function Optimization

Optimization problem according to the control function is defined in this section.

5.2.1 Cost Function

Since the implementation of optimization is to obtain a set of parameters which control the mechanism to travel with the setpoint as close as possible, the cost function is defined to be the error between setpoint and system output, which is known as the control error.

However, such control error is not only a constant, but also a time depending sequence. Thus, Integrated Absolute Error (IAE), which is always used to judge a control system, is used as the cost function. Where IAE is a constant integrating absolute control error within the time period as defined in Eq.(5.2-1).

$$IAE = \int_0^t \left| y_{sp}(t) - y(t) \right| dt = \int_0^t \left| e(t) \right| dt \qquad (5.2\text{-}1)$$

For the setpoint $y_{sp}(t)$, a most common used control signal with an elongated standing time at disengaged position is exercised as shown in Figure 4.3-7. Which is a signal disengaging the clutch in 0.1 second, and then remain disengaged for about 0.8 second for synchronizer to shift gear ratios, finally engages gradually within 0.8 second. The elongated standing time at disengaged position is used to increase the weighting of steady-state error while the clutch is actuated to the fully disengaged position. And the same weighting of time period of 0.8 second is imposed on the final section where the clutch is engaged again to the final steady-state.

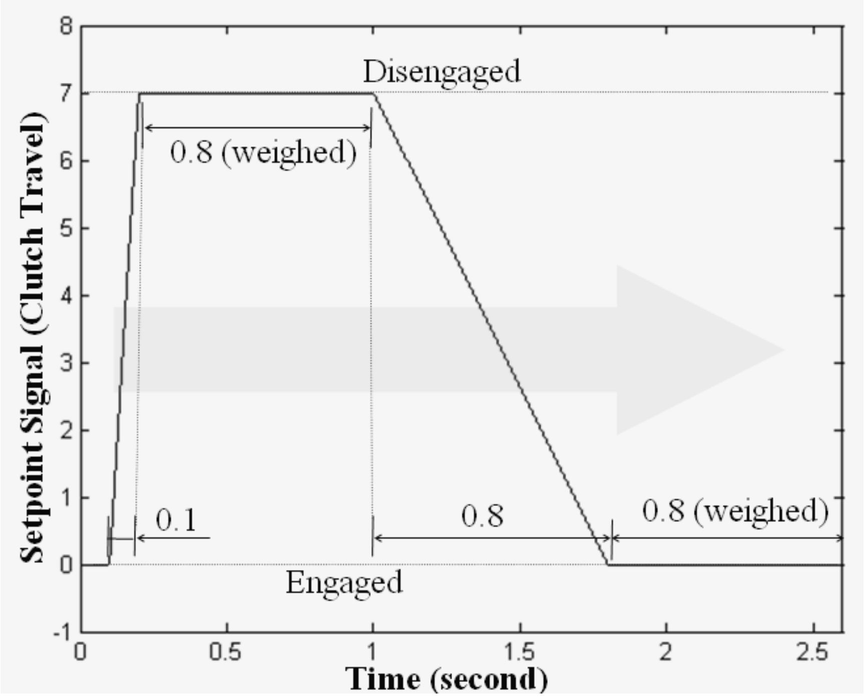

Table 5.2-1 General Setpoint Signal

5.2.2 Design Variables

The design variables are control parameters of the control function defined in section 4.2 .

There are two set of PID controls within the control function. The second PID control plant, which control current of the DC motor and designed by IMC method in subsection 4.3.1 , is well performed as shown in Figure 4.3-3. Thus the parameters within this control plant are not modified again in this chapter. The optimization of parameters in this chapter is focus on the first PID control plant, which controls position of the clutch and the first design by Z-N turning method is not well performed as shown in Figure 4.3-7 . The control function of this control plant is expressed in Eq.(4.2-6), and the control parameters, the design variables, are shown in Table 5.2-2.

Design Variables	K	T_i	T_d	N	b	c
Initial Values	*4.74*	*0.0039*	*0.000975*	*14*	*1*	*1*

Table 5.2-2 Design Variables of Control Optimization

5.2.3 Constraints

There is no absolute constraint for the PID control. However, the parameters still can’t be less then zero. Thus, the main control parameters K, T_i, and T_d are constrained to be zero to infinity, which is practicable in commercial product.

For parameters N, b, and c are mainly depends on the controller chosen. Such parameters are set within a controller. Different manufacturers with different specs provide different values of N, b, and c. The optimization on these parameters is to give a guideline for controller choice. In common commercial PID controller, N is in the range from 8 to 20, and b and c are 1 or 0.

The constraints for the design variables are summed up in Table 5.2-3.

Design Variables	K	T_i	T_d	N	b	c
Constraints	$0<K<\infty$	$0<T_i<\infty$	$0<T_d<\infty$	$8\leq N\leq 20$	*1 or 0*	*1 or 0*

Table 5.2-3 Constrains of Control Optimization

5.2.4 Optimization Implement

The optimization is implemented in Matlab® using optimization program “fmincon”, which uses SQP method to find minimum point with constraints defined as introduced in subsection 3.3.4 .

To avoid local minima, optimizations are executed several times with an increasing minimum change in design variables for finite difference derivatives “DiffMinChange”. The optimization with increasing of minimum change in difference derivative is proceeded until the system output is well fit with the setpoint. The optimizations results with different change steps are shown in Table 5.2-4. And a comparison of the results is shown in Figure 5.2-1 and Figure 5.2-2. Note that each design variables are normalized to be units in the optimizations to avoid modifications with different scales.

DiffMin.	K	T_i	T_d	N	b	c	***Cost(1e-3)***
1e-4	*4.388*	*0.00815*	*0.00105*	*20*	*1*	*1*	*235.64*
1e-3	*5.613*	*0.0185*	*0.115*	*10*	*1*	*1*	*137.21*
1e-2	*4.613*	*0.0185*	*0.117*	*18*	*1*	*1*	*136.817*
1e-1	*4.369*	*0.0447*	*0.086*	*20*	*1*	*1*	*115.51*

Table 5.2-4 Optimization Results with Different Derivative Step Size

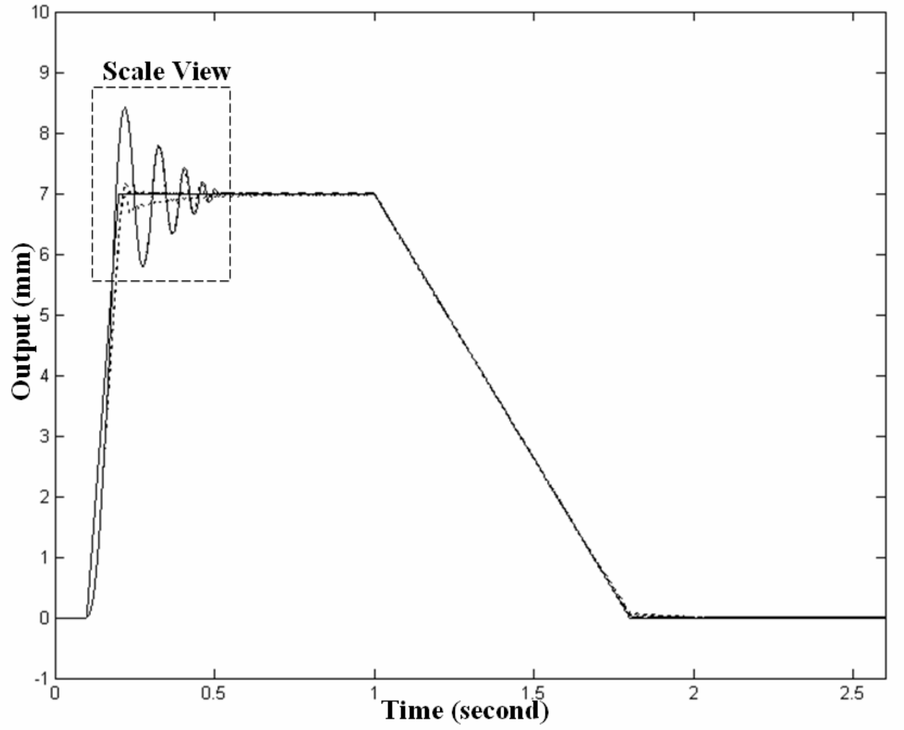

Figure 5.2-1 Optimization Results with Different DiffMinChange

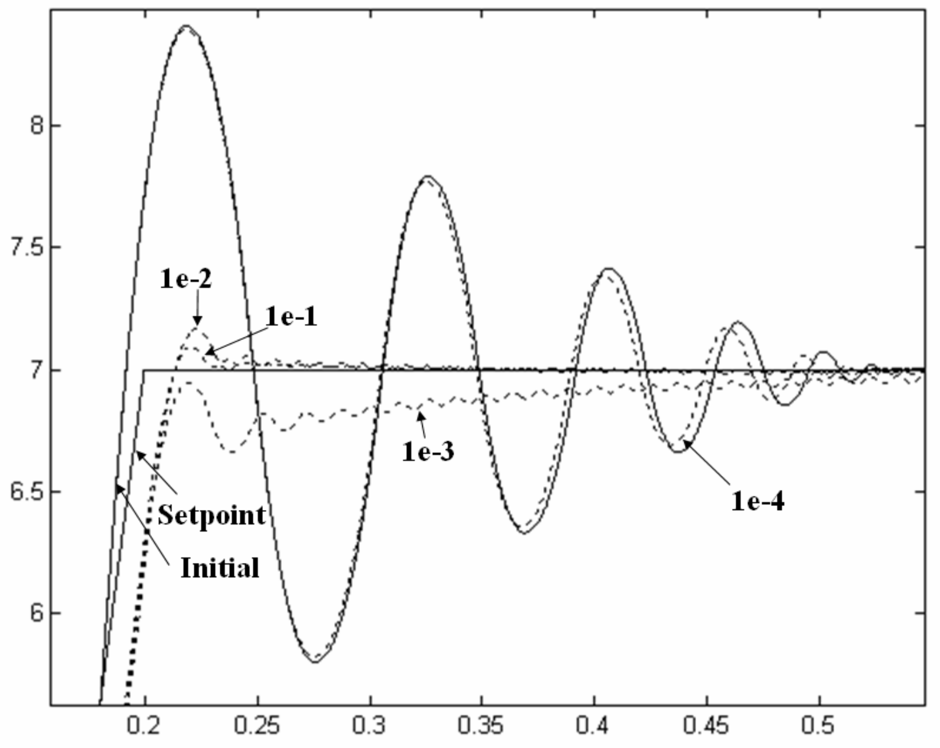

Figure 5.2-2 Scale View of Figure 5.2-1

From Figure 5.2-2, it is obvious that optimization results with minimum derivative step size of 0.01 and 0.1 provide system outputs that very fit to the setpoint and the transient states are steady with little overshoots. Whatever they are global minimum or not, the solutions are feasible for the control requirement.

The optimization result is shown in Table 5.2-5 and Figure 5.2-3, as a result from minimum derivative step size of 0.1. A comparison of initial design is also shown with a dash line in Figure 5.2-3.

	Design Variables						**Cost**
	K	T_i	T_d	N	b	c	
Initial Design	*4.74*	*0.0039*	*0.000975*	*14*	*1*	*1*	*242.7*1e-3*
Optimization Result	*4.369*	*0.0447*	*0.086*	*20*	*1*	*1*	*115.5*1e-3*

Table 5.2-5 Optimization Result

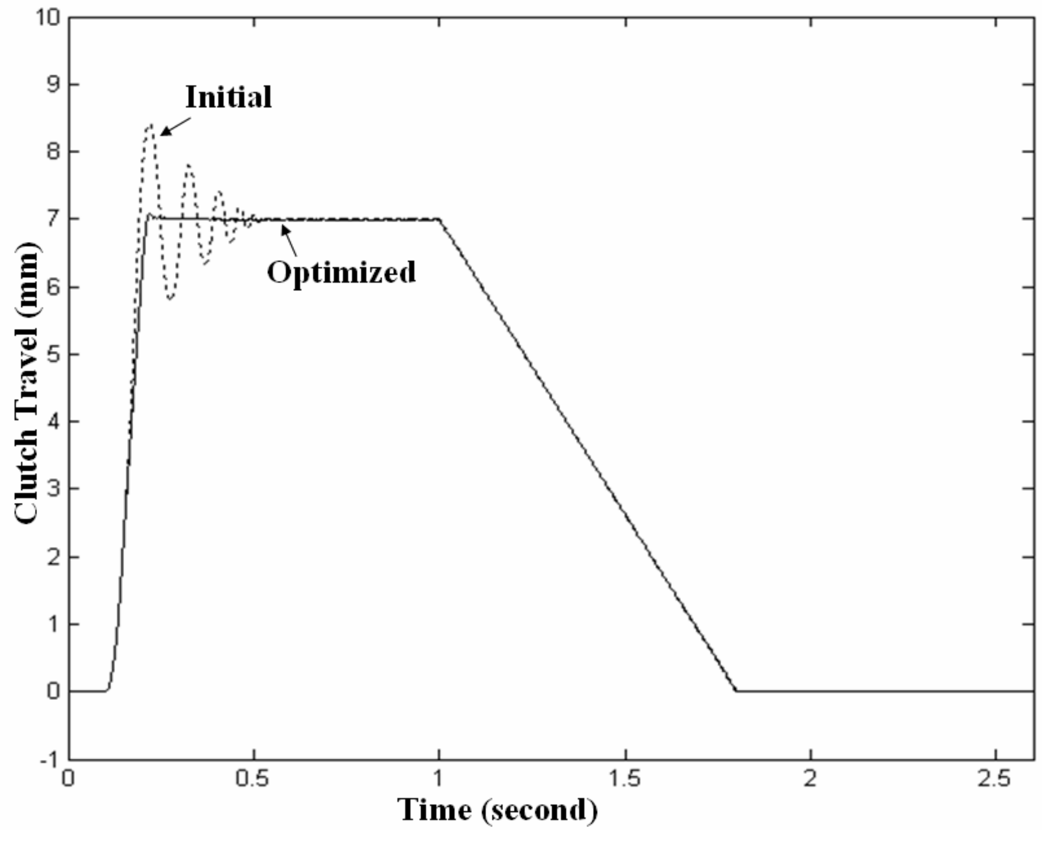

Figure 5.2-3 Optimization Result

Such result corresponds to the forecast in subsection 4.3.2 , that the proportional term K is reduced and the derivative term T_d is increased.

Figure 5.2-4 shows a condition where setpoint is modified to an irregular signal. The result shows that the mechanism is still well controlled.

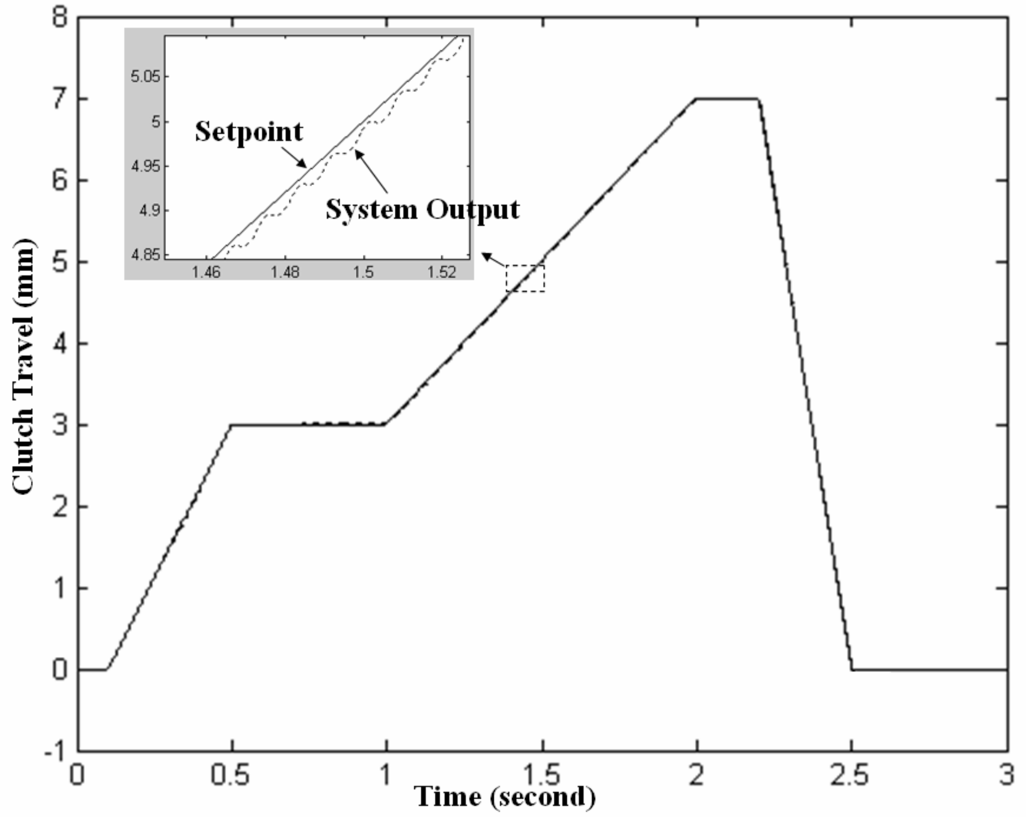

Figure 5.2-4 Modification with Irregular Setpoint

5.3 Optimized System Simulation

The simulation combining the optimized clutch actuator, the optimized control function, and the powertrain are presented in this section.

The following simulation results show a sequence of action. The vehicle starts with 1st gear ratio, and then accelerates with the engaging clutch and the increasing TPS control; the TPS is increasing with time during this time period; at about the third second, where the engine speed is about 5500 R.P.M., the ECU command decides to shift to 2nd gear ratio, a control command to clutch actuator is sent to disengage the clutch; after fully disengaged, the synchronizer begins to synchronize the next gear; after the synchronizer have finished the shifting process, the ECU gives a command to the clutch actuator to engage the clutch to the original position gradually. In order to unroll the simulation ability, another command of down-shifting is exerted at seventh second. The same disengage/engage command is issued, but instead of up-shifting to 3rd gear ratio, the command is assigned to down-shifting to 1st gear ratio to unfold an action of engine-brake.

Figure 5.3-1 and Figure 5.3-2 show the setpoint signal and the TPS control signal. And Figure 5.3-3 shows the shifting signal.

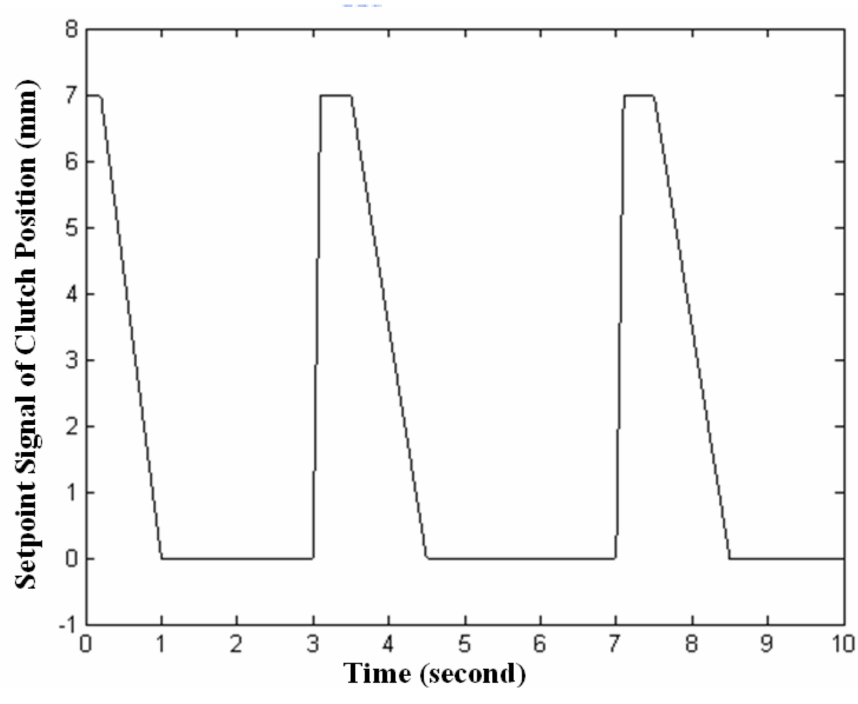

Figure 5.3-1 Setpoint Signal of Clutch Position

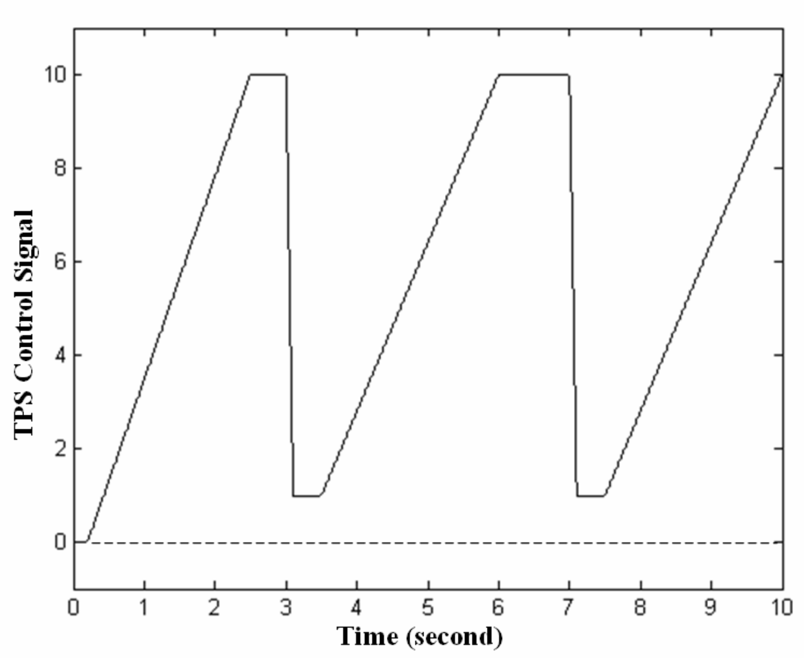

Figure 5.3-2 TPS Control Signal

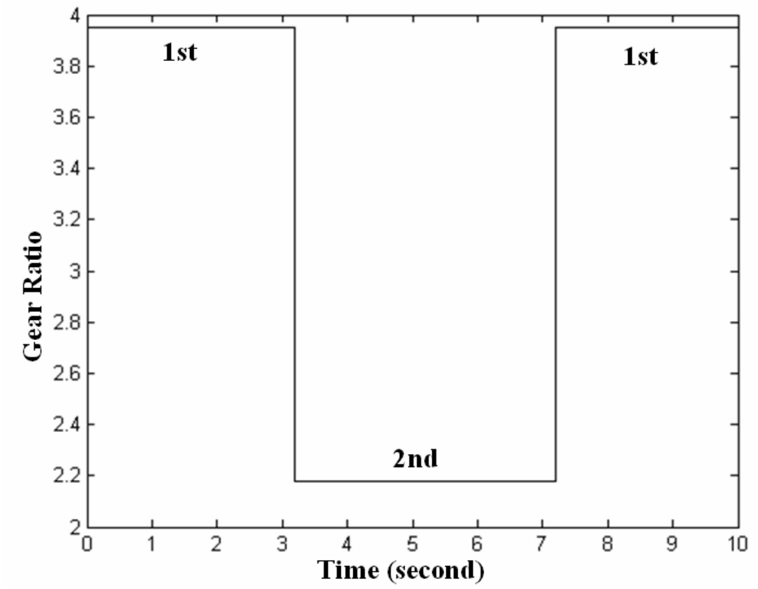

Figure 5.3-3 Shifting Signal

Figures below show the simulation results. Figure 5.3-4 shows the locus of clutch travel, Figure 5.3-5 shows torque generated by the engine, Figure 5.3-6 shows the torque transmit-ability of the clutch, Figure 5.3-7 shows the vehicle speed, Figure 5.3-8 shows the vehicle acceleration, Figure 5.3-9 shows the engine speed, and Figure 5.3-10 shows the engine acceleration. Note that clutch is fully disengaged with travel distance of 5.9mm in reality, and TPS starts to increase after the clutch is fully disengaged.

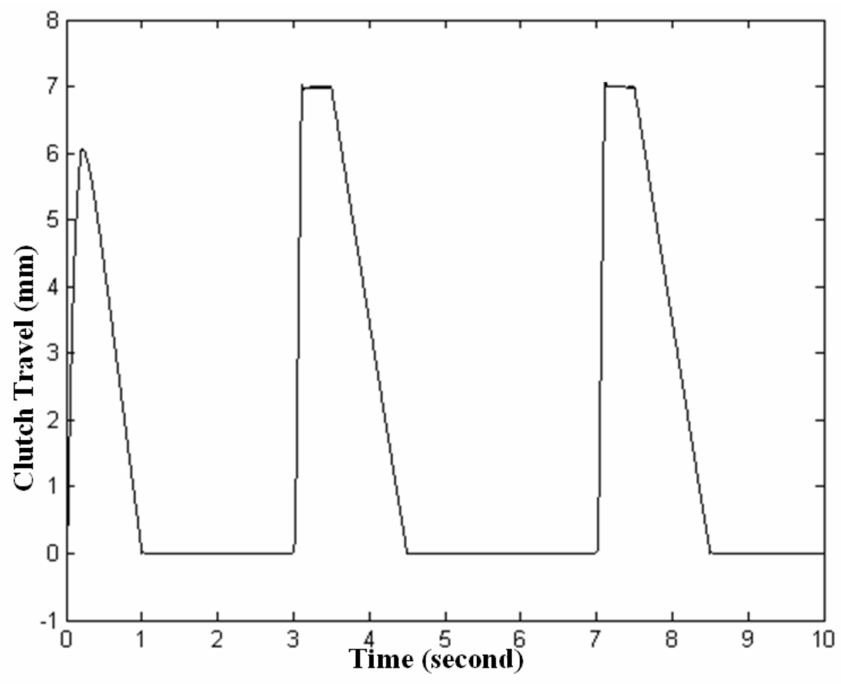

Figure 5.3-4 Clutch Travel

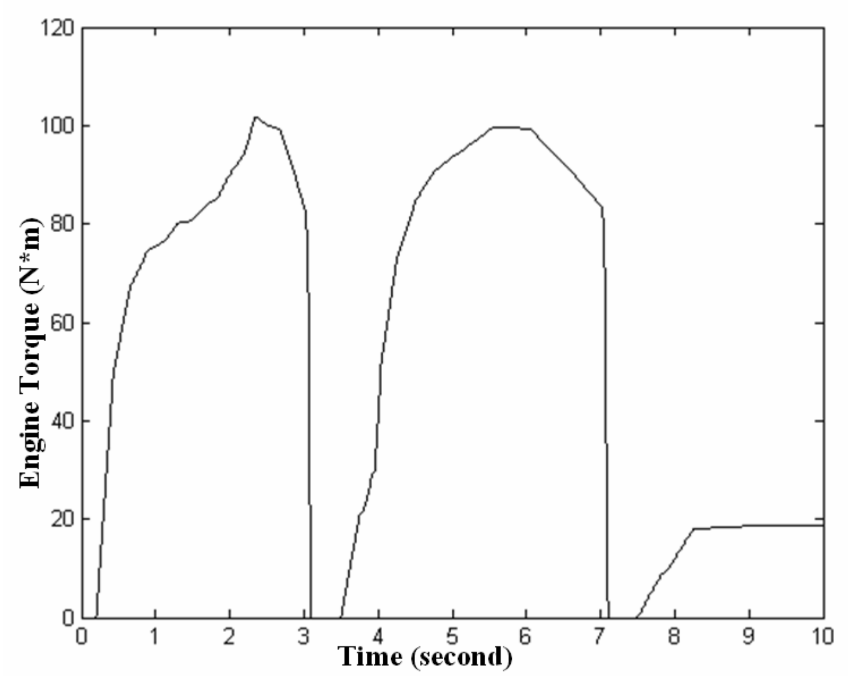

Figure 5.3-5 Engine Torque

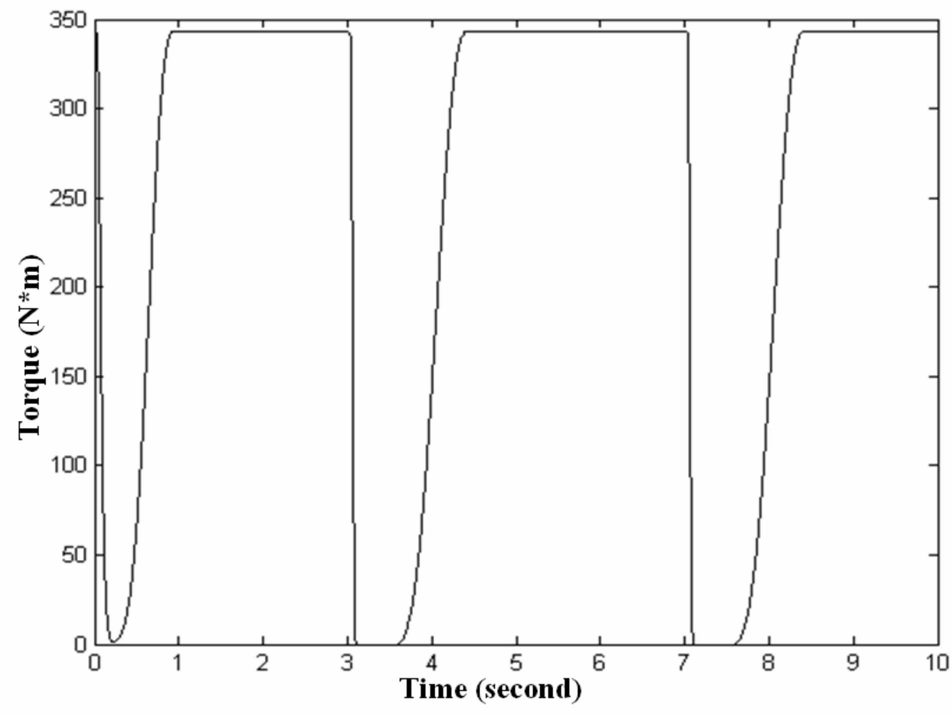

Figure 5.3-6 Torque Transmit-Ability of the Clutch

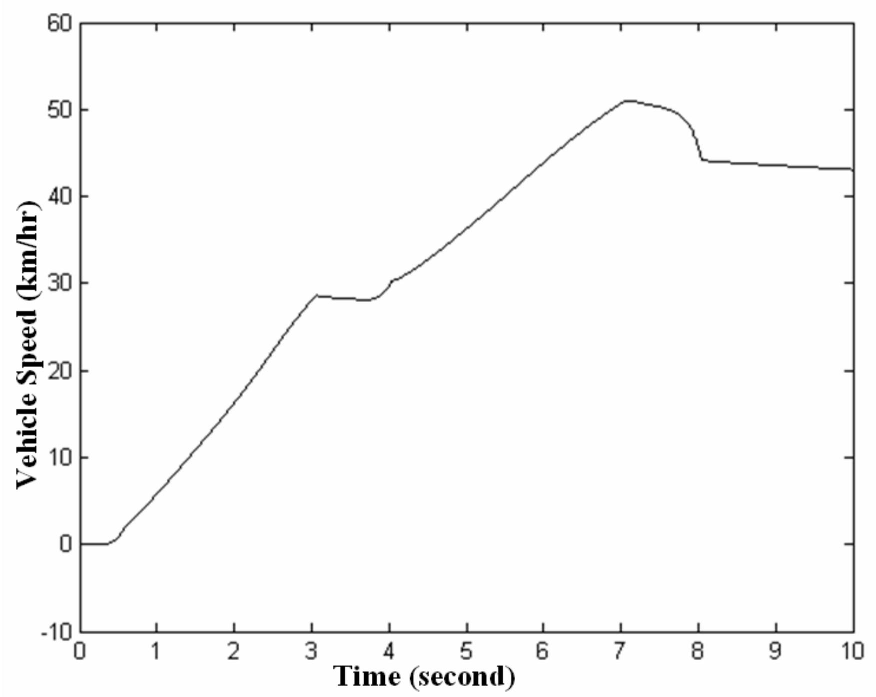

Figure 5.3-7 Vehicle Speed

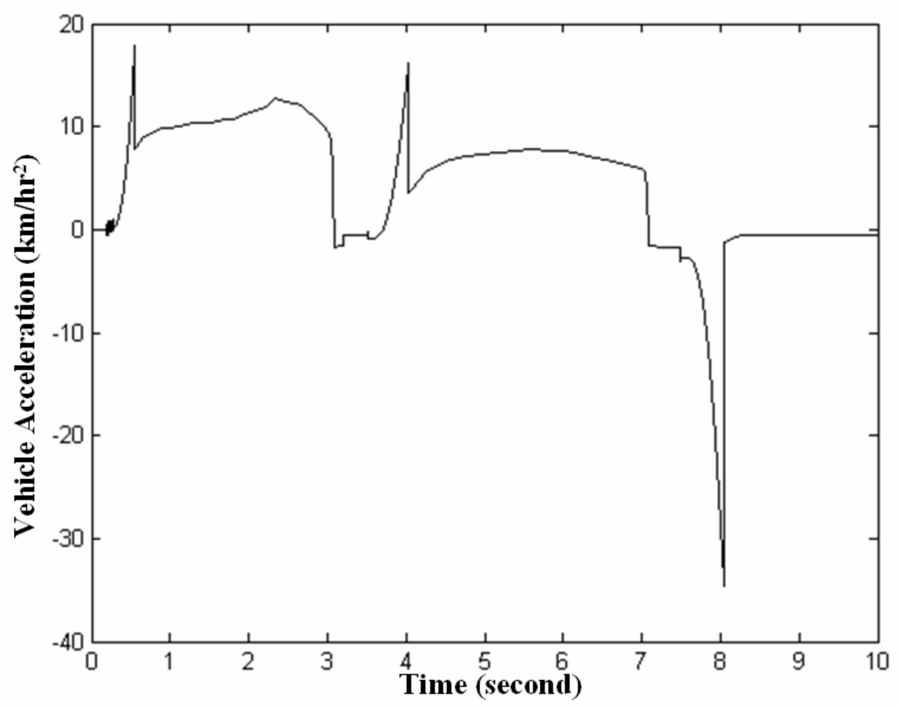

Figure 5.3-8 Vehicle Acceleration

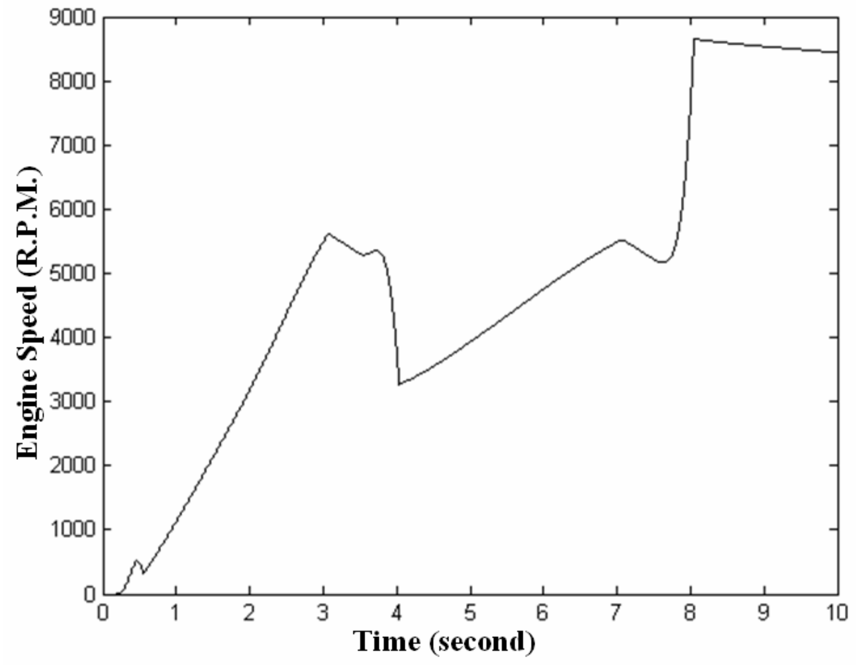

Figure 5.3-9 Engine Speed

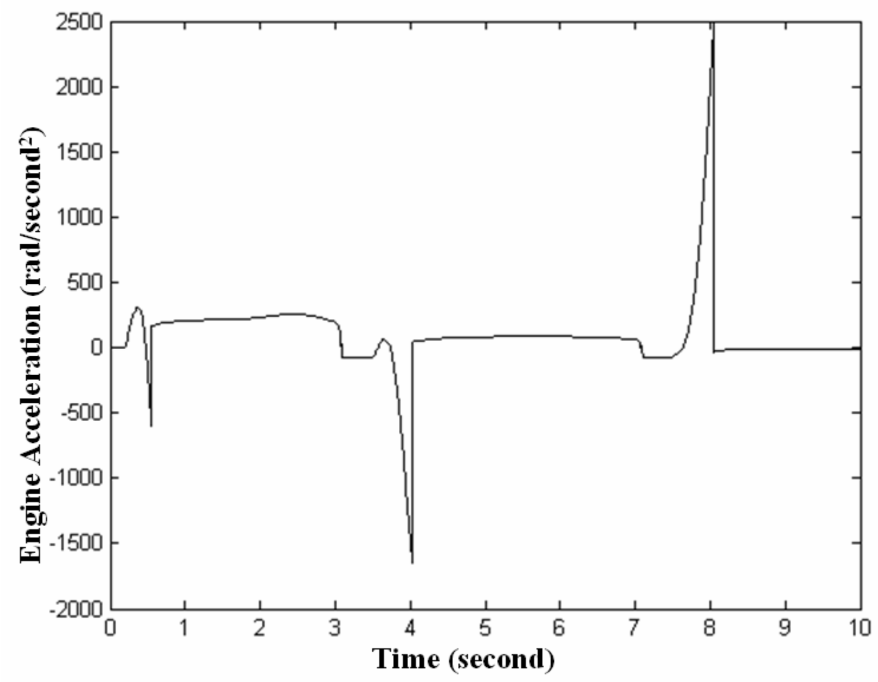

Figure 5.3-10 Engine Acceleration