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MODELING AND SIMULATION OF GEAR SHIFT CONTROL FOR THE U340 AUTOMATIC TRANSMISSION USING MATLAB–SIMULINK AND STATEFLOW

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Abstract

This study presents the modeling and simulation of shift control for the U340 automatic transmission using MATLAB–Simulink and Stateflow software based on a model-based design approach. The objective of this study is to build a system-level model combining physical blocks (engine, hydraulic torque converter, CR–CR planetary gearbox, powertrain – vehicle) and electro-hydraulic control blocks to evaluate the shift pattern, performance, and smoothness of the shifting process. The torque converter is modeled through dimensionless characteristics in the form of lookup tables in Simulink, while the transmission is simulated with discrete gear ratios corresponding to the closed/open states of the clutches and brakes. Simulation scenarios were performed in two cases: changing throttle opening while the vehicle was running on a flat road and fixing throttle opening but changing the simulated rolling resistance torque to simulate steep road conditions. Simulation results show that the model accurately simulates the shifting pattern of the U340 transmission; turbine shaft torque is significantly amplified in the low speed ratio range, improving acceleration capability, while pressure regulation and torque converter lock-up reduce speed fluctuations, enhancing transmission efficiency and smoothness during shifting. The proposed model can be used as an effective tool in research, teaching, and optimization of automatic transmission control strategies, as well as extended to more modern power transmission systems.

Keywords: *U340 automatic transmission; hydraulic torque converter; MATLAB–Simulink; Stateflow; shift control; performance; smoothness.*

1. Introduction

The development of automatic transmissions (AT) over the past half-century shows a shift from purely hydraulic-mechanical structures to highly integrated mechatronic systems, aiming to simultaneously optimize shift smoothness, energy efficiency, and powertrain durability [1–3]. The theoretical foundation of automotive dynamics, power transmission principles, and powertrain design has been systematized in classic English and Vietnamese literature, providing a solid basis for modeling and calculation studies at the system level [2], [4–6]. At a detailed level, gear kinematics and dynamic loading on teeth provide an in-depth picture of torque transmission behavior, disturbances, and vibrations in power transmission, particularly useful when evaluating shift quality and noise, vibration, and harshness (NVH) of planetary mechanisms [13–16].

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In terms of control, the problem of determining and optimizing shift timing has been extensively studied with various approaches: from classical rule-based control to performance/acceleration optimization strategies, emphasizing smoothness constraints and friction element durability [7]. Additionally, modeling and controlling the transmission within the perspective of an integrated powertrain system with the engine is considered key to ensuring harmony between fuel efficiency, dynamic response, and smooth shifting [8–9]. Another important axis is the characteristics of the torque converter (TC)—the component that determines starting ability, acceleration, and shock absorption—with three characteristic quantities: speed ratio, torque transmission ratio, and efficiency, which directly govern the torque at the turbine shaft and shift behavior under different load modes [10–12].

The planetary gearset in AT—particularly the CR–CR configuration—enables discrete gear ratios by coordinating clutches/brakes according to control states; quantifying the Willis relationship between elements (sun, ring, pinion) is fundamental to deriving the transmission ratio and speed constraints at each gear [13–16]. At the tool level, MATLAB–Simulink and Stateflow have become the de facto standard for Model-Based Design (MBD) in the automotive industry, thanks to their ability to simulate continuous–discrete hybrid systems, use lookup tables for motor/transducer characteristics, and implement finite state machines (FSM) for ECT shift logic (Electronic Controlled Transmission) [17–19]. Concurrently, TC models on MATLAB/Simulink and ECT simulations at the system level have been validated through numerous studies, reinforcing the effectiveness of the MBD approach in developing shift strategies [20–22].

In this context, supervisory control approaches for powertrains, including human-machine structures and optimal/heuristic control, continue to expand their scope of application from traditional vehicles to intelligent-connected systems [23–26]. In Vietnam, many domestic projects have modeled the transmission shift process and the dynamics of AT vehicles, creating a database and implementation experience suitable for operating conditions, although they are still scattered and vary in detail [27–30]. The international research community has also strongly promoted model-based design for AT controllers (from rules to optimization), demonstrating the ability to quickly convert from simulation to testing [31–32]. Going further, the requirement to optimize shift schedules to improve fuel consumption and acceleration has been approached from the perspectives of optimal control, multi-objective control, and adaptive control [33–37], as well as overviews of fuel economy and emission reduction strategies in the context of modern transportation [39–41].

At the hardware and implementation level, the ECT system with S1/S2 shift valves, SLT/SLU linear valves, and accumulators plays a decisive role in smooth shifting, hysteresis to prevent hunting, and lock-up at high speeds. Understanding the pressure behavior and element constraints is a prerequisite for modeling and calibrating shift laws in simulation [42]. From a modern control perspective, the control-optimization platform (classical and advanced) provides a comprehensive toolkit for forming upshift/downshift threshold maps based on throttle opening/road load, with smooth constraints and sustainability [43–46]. In terms of system simulation, the mechatronics dynamics-simulation method provides an

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integrated framework for linking the engine-TC-transmission-vehicle-ECT, supporting the verification of shift maps and operating scenarios before deployment on test vehicles [47], [50–51]. Additionally, assembly strategies to reduce planetary gear whine remain an important NVH criterion that must be considered alongside control objectives [52]. The Vietnamese literature on automotive theory and design continues to be a valuable practical reference, facilitating the localization of models and input data [53–58].

Despite accumulated results, three practical gaps remain. First, most research focuses on ATs in general, lacking case studies closely aligned with the U340 transmission code—a common configuration in B/C-segment vehicles—to serve as a reference framework for training and research [27–30]. Second, many models separate the engine–TC and ECT logic, making it difficult to quantify the impact of pressure (SLT), TC lockup (SLU), and hysteresis on smooth shifting in diverse load/throttle scenarios [31–32], [33–37]. Third, quite a few simulations use generic characteristics, while designing a usable shift law requires detailed engine and TC characteristics to build upshift/downshift threshold maps based on throttle opening and road conditions [39–41], [43–46], [47], [50–51].

To fill these gaps, this paper aims to develop a system-level simulation model for the U340 transmission based on MATLAB–Simulink/Stateflow, fully connecting the Engine–TC–Gearbox–Vehicle with ECT–FSM, thereby evaluating shift rules and shift quality under typical operating scenarios. Specifically, the paper (i) standardizes the theoretical foundation for the TC and CR–CR planetary gear, (ii) develops a hierarchical Simulink model with lookup tables for TC/engine, (iii) designs an ECT FSM with hysteresis and a conditional TC lock, and (iv) runs simulations under scenarios of varying throttle opening and load resistance to derive shift maps and quantitative observations on smoothness, performance, and acceleration response.

2. System Model

2.1. Overall Structure of the Powertrain System

The vehicle's powertrain system uses a U340 automatic transmission comprising the following main assemblies: gasoline engine, torque converter (TC), CR–CR type dual planetary transmission assembly, clutch and brake control elements (C1–C3, B1–B3, F1–F2), differential, and drive wheels. The overall diagram is illustrated in Figure 1 – Diagram of the vehicle's powertrain system with automatic transmission.

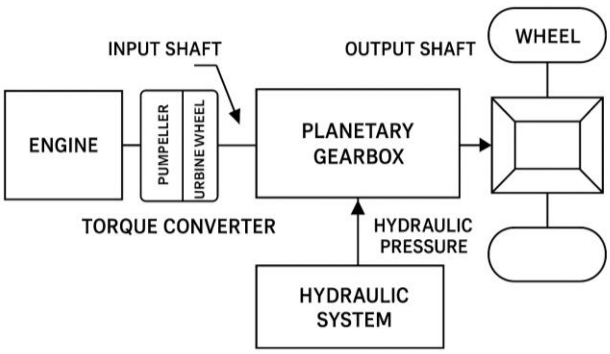

Figure 1. Transmission system diagram of a vehicle with an automatic transmission

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In this system, the torque converter functions to transmit and amplify torque from the engine to the primary shaft of the transmission when the vehicle starts or when there is a sudden increase in load, while also helping reduce shock and isolate torsional vibrations between the engine and the drivetrain. The planetary gearset is responsible for changing the gear ratio, enabling the vehicle to achieve different speed modes by opening/closing the clutch and brake elements according to the transmission ECU (ECT-ECU) command.

The ECT (Electronic Controlled Transmission) system receives signals from multiple sensors (engine speed, throttle position, vehicle speed, oil temperature, etc.), thereby determining the shift strategy, controlling oil pressure, and locking the torque converter via solenoid valves in the valve body. This entire process ensures smooth shifting, fuel economy, and optimal engine power.

2.2. Basic characteristics of the hydraulic torque converter

The hydraulic torque converter in the U340 transmission has three basic characteristics: torque transmission ratio, speed transmission ratio, and efficiency, which are the parameters that determine the transmission behavior between the engine and the transmission.

2.2.1. Torque transmission ratio of the torque converter

The torque transmission ratio of the torque converter is calculated using the following formula.

$$I_M = \frac{M_2}{M_1} \quad (1)$$

The torque transmission ratio of the torque converter depends on the operating conditions of the torque converter. When the moving resistance force increases, the number of revolutions of the turbine shaft decreases, leading to an increase in M_2, thus increasing I_M. It has the largest value when the turbine wheel is stationary, i.e., $n_2 = 0$. Conversely, when the moving resistance decreases and the vehicle speed increases, the transmission ratio of the variable transmission decreases.

2.2.2. Speed ratio of the transmission

The transmission ratio of the variable speed drive (i_{bm}) is the ratio between the rotational speed of the turbine shaft n_2 and the rotational speed of the pump shaft n_1.

$$i_{bm} = \frac{n_2}{n_1} \quad (2)$$

Where: n_2 is the turbine wheel speed;

n_1 is the pump wheel speed.

2.2.3. Efficiency of the gearbox

The efficiency of the variable speed drive is calculated as follows:

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$$\eta = \frac{N_2}{N_1} = \frac{n_2.M_2}{n_1.M_1} \tag{3}$$

Where: N_2: Power output on the turbine shaft of the variable speed drive;

N_1: Power on the pump shaft of the variable speed drive.

The efficiency of the variable speed drive indicates how much energy is effectively transferred from the pump blades to the turbine blades.

2.2.4. Sensitivity coefficient

The sensitivity of the hydraulic variable is characterized by the coefficient λ:

$$\lambda = \frac{\lambda_1}{\lambda_1^{'}} \tag{5}$$

Where: $\lambda_1^{'}$: Torque conversion coefficient at the turbine wheel's rotational speed.

λ_1 : Torque variation coefficient at turbine wheel rotational speed n2= 0.

2.3. Developing the engine-transducer coordination characteristic

From the local characteristic curve of the motor, the coordination characteristic between the motor and the variable speed drive can be determined, allowing the calculation of the output torque of the variable speed drive under different operating conditions.

The basic parameters characterizing the hydraulic torque converter include:

Input torque of the torque converter: $M_1 = \lambda_1 \gamma n_1^2 D_a^5$

Variator coefficient: $k = \frac{M_2}{M_1}$

Transmission ratio: $i_{bm} = \frac{n_2}{n_1}$

Efficiency: $\eta = \frac{N_2}{N_1} = \frac{M_2\omega_2}{M_1\omega_1}$

Where:

γ is the specific gravity of the working fluid: the U340E gearbox uses Dexron II oil with γ = 850 kg/m³;

M_2 is the output shaft torque of the variable speed gearbox;

$\lambda_1$is the moment coefficient on the pump wheel, determined experimentally. Referring to the dimensionless characteristic curve, we obtain $\lambda_{max} = 2.7 \times 10^{-6}$ ph^2/vg^2;

n_1, n_2 are the rotational speeds of the input and output shafts of the variable speed drive (n1= ne);

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D_a is the effective diameter of the variable speed drive D_a = 225 mm.

Since the U340 variable speed drive is a sensitive type, the torque coefficient on the pump wheel changes. To determine M_1, we must determine the values of λ_1, so for each value of λ_1,we can plot a line M_1. From the dimensionless characteristic curve of the variable motor, we determine the values of λ_1 corresponding to each value of the transmission ratio of the variable motor i_{bm}.

3. Simulation and Results

3.1. Simulation Modes

Data on the vehicle and powertrain system used in calculations

No.	Description	Unit	Value
1	Vehicle mass	kg	1650
2	Distributed to the front axle	kg	910
3	Engine displacement	cm^3	1975
4	Wheel radius	m	0.282
5	Gear ratio of 1st gear		2.848
6	Gear ratio of 2st gear		1.553
7	Gear ratio of 3st gear		1
8	Gear ratio of 4st gear		0.701
9	Reverse gear		2.343
10	Engine moment of inertia	$kg \cdot m^2$	0.087
11	Pump impeller moment of inertia	$kg \cdot m^2$	0.058
12	Turbine wheel moment of inertia	$kg \cdot m^2$	0.05623

The test modes include:

- Gearshift pattern corresponding to vehicle speed and engine load.

- Investigation of the vehicle's traction characteristics corresponding to control modes (different throttle openings).

3.2. Some results and analysis

Shift patterns corresponding to varying engine load and vehicle speed.

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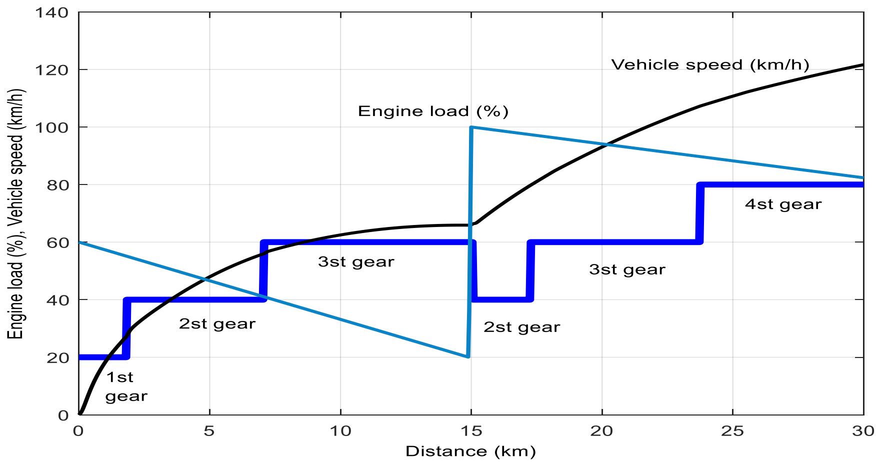

Figure 2. Gear shift graph with varying engine load and constant drag torque

When the vehicle is traveling on a straight road with constant resistance and the driver wants to accelerate quickly (e.g., to overtake another vehicle), the driver suddenly increases throttle, causing the vehicle to downshift to a lower gear to increase traction torque, as shown in Figure 2.

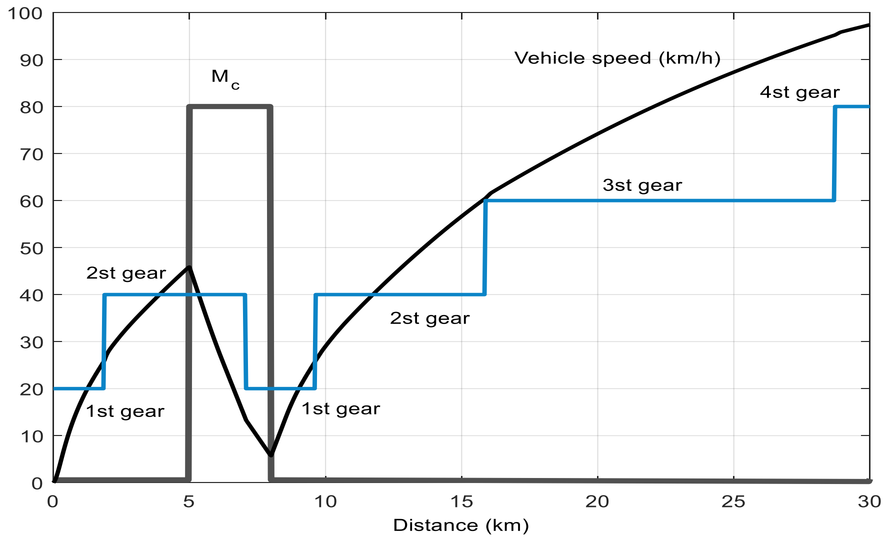

Figure 3. Gear shift graph with constant engine load (α=50%) and varying drag torque Mc

When the vehicle is running with constant engine load and the speed decreases due to high resistance torque (e.g., when climbing a hill), the driver keeps the accelerator pedal depressed, at which point the vehicle must shift to a lower gear to increase traction torque to overcome the resistance, as shown in Figure 3.

Figures 4 and 5 show the torque characteristics of the engine Me and the torque on the turbine shaft M2 corresponding to the values of the constant throttle opening during operation.

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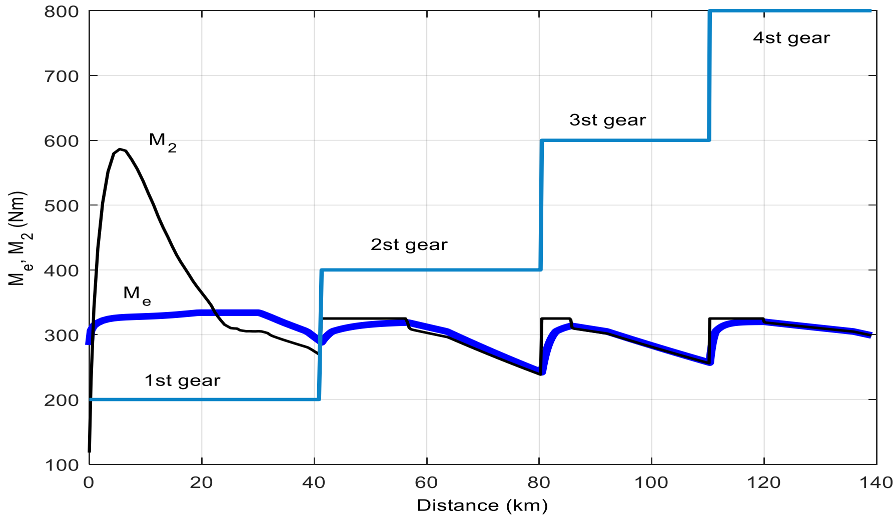

Figure 4. Graphs of Meand M2(α=100%) moving on a flat straight road

It is observed that at the 100% throttle position, v = 40 km, the vehicle shifts from 1st gear to 2nd gear. When v = 80 km, the vehicle shifts from 2nd gear to 3rd gear. When v = 110 km, the vehicle shifts from 3rd gear to 4th gear. This corresponds to the established gear shift strategy.

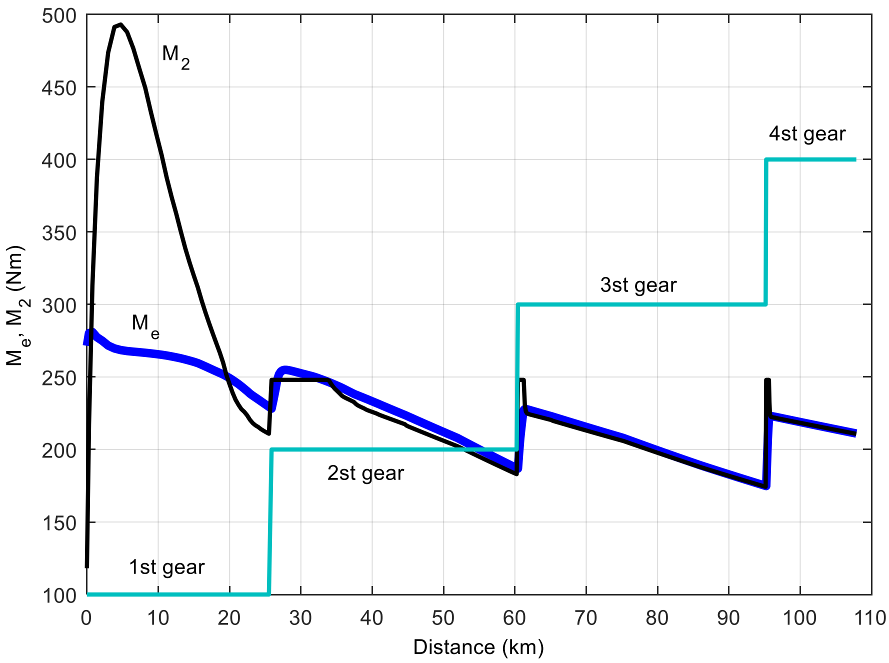

Figure 5. Graphs of Meand M2(α=50%) moving on a flat straight line

It is noted that at 100% throttle position, v = 23 km/h, the vehicle shifts from 1st gear to 2nd gear. When v = 60 km/h, the vehicle shifts from 2nd gear to 3rd gear. When v = 90 km/h, the vehicle shifts from 3rd gear to 4th gear. This aligns with the established gear-shifting strategy.

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From the two graphs, we see that when the vehicle is at (α=100%), the torque generated is larger but the gearshift speed is high, and when the vehicle is at (α=50%), the torque generated is smaller but the gearshift speed is low.

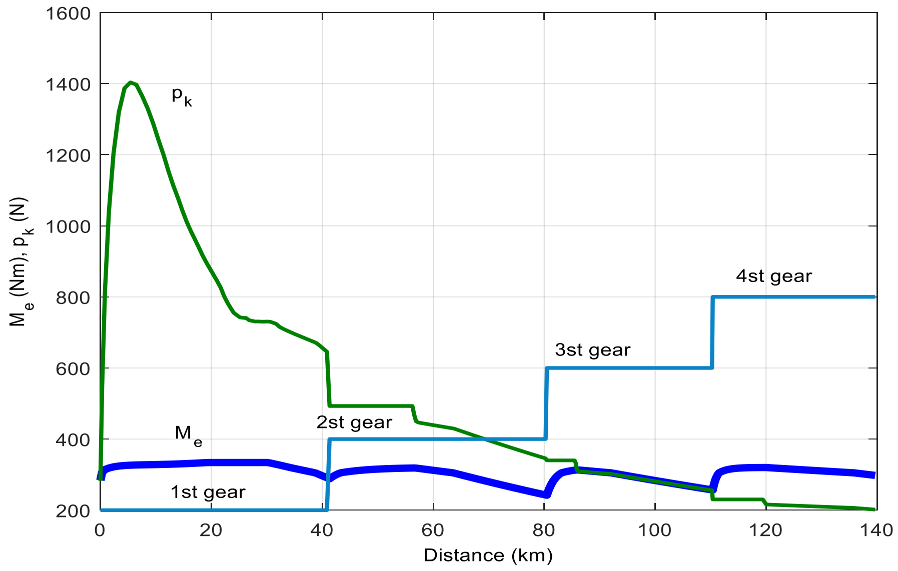

Figure 6. Graphs Meand pk(α=100%)

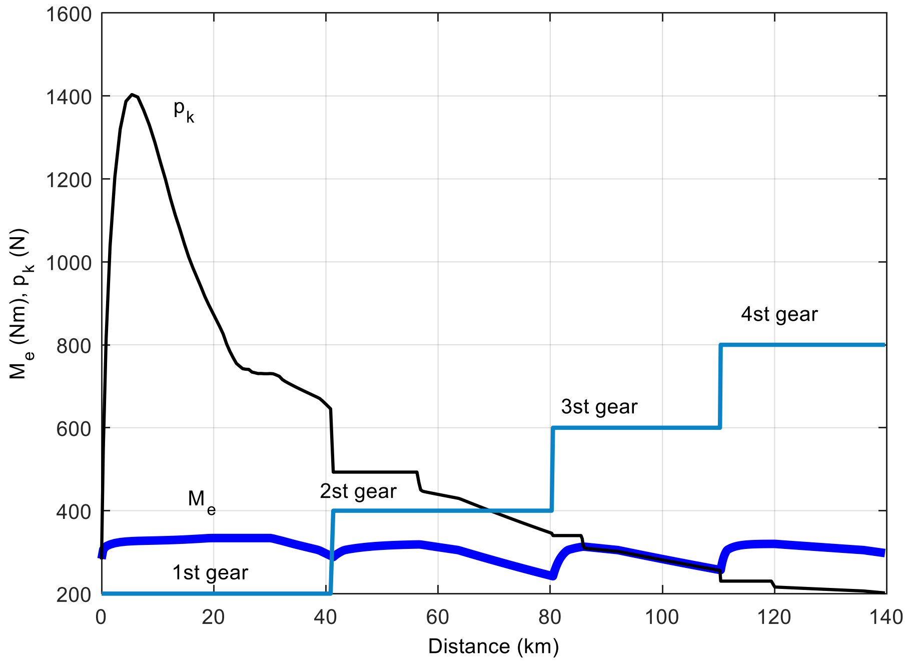

Figure 7. Graphs of Meand pk(α=50%)

Based on the results of Figures 6 and 7, we observe:

The traction force at the gear shifts fluctuates continuously (unlike the traction force graphs in the case of using a conventional mechanical transmission), thereby reducing the loss of vehicle speed during the gear shift process.

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When the engine load is higher, greater traction force and higher shift speed are generated, enabling faster acceleration.

From the simulation results, we derive the following operational experience:

When using an automatic transmission, it is advisable to accelerate gradually rather than abruptly, as abrupt acceleration may cause downshifting instead of upshifting.

5. Conclusion

This study presents the modeling and simulation process of the U340 automatic transmission gear shifting control on the MATLAB–Simulink and Stateflow platform, based on the Model-Based Design (MBD) method. The model was constructed with a closed-loop system structure, including physical blocks (engine, hydraulic torque converter, planetary gearbox, transmission, and vehicle) along with an electro-hydraulic control unit (ECT) designed using a finite state machine (FSM). This structure allows detailed simulation of the interaction between the mechanical system and electronic control, fully reflecting the torque, speed, and pressure transformation processes throughout the shift cycle.

Simulation results show that the model accurately reproduces the shift pattern of the U340 transmission under different operating conditions. As throttle opening increases, the model clearly reflects the change in shift timing, ensuring the engine operates in the efficient torque range; when load resistance increases, the system automatically downshifts to increase traction, consistent with actual control strategies. In particular, thanks to detailed modeling of the hydraulic torque converter, the study revealed a marked torque amplification in the low speed ratio range, helping the vehicle accelerate faster and more stably. The pressure regulation and torque converter lock-up processes integrated in the ECT controller help reduce vibration and speed fluctuations, improving smoothness and power transmission efficiency during gear shifting.

In terms of application, the proposed model can be used as an effective tool in teaching and research, particularly in the fields of simulation, optimization, and control strategy tuning for automatic transmissions. Additionally, the model structure can be easily expanded to apply to more multi-speed automatic transmissions (6–8 speeds) or hybrid powertrain systems, as well as to integrate intelligent control algorithms (fuzzy, neural, adaptive) to enhance adaptability to actual operating conditions.

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