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Development of MATLAB Code for Gear Ratio Design and Evaluation in Vehicle Transmission Systems

Yosua Heru Irawan[1], Hao-Tian Gu[2]
[1] Department of Mechanical Engineering, Institut Teknologi Nasional Yogyakarta, Indonesia
[2] Department of Mechanical Engineering, National Taiwan University of Science and Technology, Taiwan
Correspondence: yhirawan@itny.ac.id

ABSTRAK

Makalah ini menyajikan pengembangan kode MATLAB untuk perancangan dan evaluasi rasio gigi dalam sistem transmisi kendaraan, dengan tujuan mengoptimalkan akselerasi dan efisiensi bahan bakar. Kode MATLAB ini mencakup analisis daya mesin, torsi, dan gaya hambatan untuk menghitung performa rasio gigi serta mensimulasikan kinerja kendaraan. Hasil pengujian menunjukkan bahwa kode MATLAB yang dikembangkan berhasil memprediksi dinamika kendaraan, termasuk kecepatan maksimum dan performa akselerasi pada berbagai rasio gigi. Desain pengujian memperlihatkan bahwa kendaraan mampu mencapai kecepatan tertinggi 285 km/jam pada gigi ke-5, melebihi persyaratan desain, sambil mempertahankan akselerasi yang efisien di seluruh rentang gigi. Kode ini juga cocok digunakan dalam lingkungan pendidikan, memberikan siswa dan dosen metode yang efektif untuk mempelajari dan meningkatkan sistem transmisi kendaraan. Penelitian di masa depan dapat lebih lanjut mengeksplorasi penerapannya dalam optimalisasi sistem di bidang teknik otomotif.
***Kata kunci**: Rasio gigi, kode MATLAB, sistem transmisi, akselerasi kendaraan.*

ABSTRACT

This article presents the development of a MATLAB code for the design and evaluation of gear ratios in vehicle transmission systems, with the objective of optimizing acceleration and fuel efficiency. The MATLAB tool incorporates analysis of engine power, torque, and resistance forces to calculate gear ratios and simulate vehicle performance. Test results indicate that the developed MATLAB code successfully predicts vehicle dynamics, including maximum speed and acceleration performance across different gear ratios. The test design shows that the vehicle can achieve a top speed of 285 km/h at 5th gear, which exceeds design requirements, while maintaining efficient acceleration throughout the range of gears. This code is also suitable for use in educational settings, providing students and lecturers with a powerful method to study and enhance vehicle transmission systems. Future work can further explore its applications in system optimization in automotive engineering.
Keyword : Gear ratio, MATLAB code, transmission system, vehicle acceleration.

INTRODUCTION

Gear ratio design and evaluation play a crucial role in optimizing the performance of vehicle transmission systems. Transmission systems are responsible for converting engine power into motion by controlling the relationship between engine speed and wheel speed. The design of gear ratios impacts key vehicle performance factors such as acceleration, fuel efficiency, and top speed. In a well-designed transmission system, lower gears offer more torque and power for acceleration, while higher gears provide efficiency and stability at high speeds. Thus, selecting the appropriate gear ratios is critical for balancing performance with energy consumption, making it an essential focus for both engineers and researchers in the automotive industry[1-2].

MATLAB, a widely used computational tool, has proven to be effective in addressing complex engineering challenges, including gear ratio design. It offers robust simulation capabilities, powerful algorithms, and user-friendly programming interfaces that allow engineers to model and simulate real-world systems with high accuracy. MATLAB's flexibility also enables it to be used in the analysis of vehicle transmission systems by providing tools to calculate engine power, torque, resistance forces, and velocity under various conditions [3-4]. The ease of integrating complex formulas and vehicle dynamics into MATLAB models makes it an ideal platform for developing comprehensive solutions for transmission system evaluation and design[5].

In recent years, several studies have explored the application of MATLAB in automotive transmission design. Research by Eckert et al. (2022) introduced a MATLAB-based model for analyzing multi-speed transmission systems, focusing on fuel efficiency improvements [6]. Similarly, Qi et al. (2017) developed a MATLAB simulation for optimizing shift points in automatic transmissions, which resulted in enhanced vehicle performance and energy savings [7]. Moreover, Massey (2016) investigated gear ratio optimization in electric vehicles using MATLAB, showing significant improvements in acceleration and energy consumption [8]. These studies emphasize the growing reliance on MATLAB as a tool for refining transmission systems, highlighting its versatility and accuracy.

Further research has examined various aspects of gear ratio design and transmission system analysis. For instance, a study by Jawad and Ali (2020) compared traditional transmission systems with continuously variable transmissions (CVTs) using MATLAB simulations, showing how CVTs can improve fuel economy at varying speeds [9]. Another study by Kulkarni et al. (2007) focused on the development of a MATLAB model for dual-clutch transmission systems, revealing significant improvements in shift time and fuel efficiency [10]. These investigations provide a foundation for the current study, showcasing MATLAB's ability to model different types of transmissions while addressing performance criteria such as acceleration, top speed, and fuel economy.

The objective of this study is to develop a MATLAB code that designs and evaluates gear ratios in vehicle transmission systems. This code is intended to serve as a practical tool for students and lecturers, offering a simplified yet comprehensive means to study transmission system behavior under various operating conditions. By using this MATLAB code, users can analyze the relationship between engine parameters and vehicle performance, facilitating a deeper understanding of the impact of gear ratio design on acceleration and fuel efficiency. This study aims to provide a valuable educational resource while contributing to ongoing research efforts in the field of automotive engineering.

RESEARCH METHOD

The primary objective of this research is to develop a MATLAB-based tool for designing and evaluating gear ratios in a vehicle's transmission system. The tool is aimed at optimizing both acceleration and fuel efficiency under different driving conditions. The MATLAB code is designed to compute critical vehicle performance metrics such as acceleration and velocity. The system under investigation is a manual transmission system for a 2005 BMW 325i SE, with the following Engine Torque Curve.

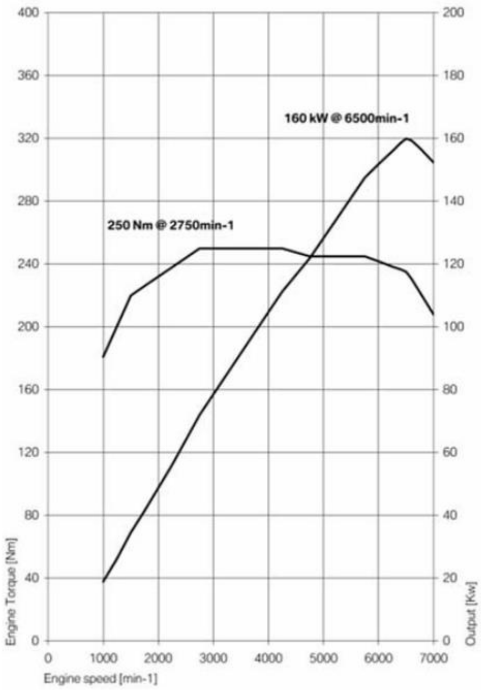

Figure 1. The engine specification of BMW N52 325i (Euro 2.5i).

The optimal gear ratio must be determined so the traction does not exceed the traction limit. Besides that, we also have to pay attention to the many parameters of the vehicle that affect its performance. The MATLAB code was developed to simulate vehicle performance using the following approach:

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1. Calculate the wheel radius from known standard tires symbol 205/55 R 16 W. From this symbol we can use rim diameter 16 in (406.4 mm), tire width 205 mm, and aspect ratio (tire height/tire width) 55%.

$$r = tire\,height + \frac{rim\,diameter}{2} \quad (1)$$

2. Extract torque data *T* for each RPM from Figure 1.
3. Define the vehicle mass *m* with driver, passenger, and cargo.
4. Calculate the gear ratio *n* (1st, 2nd, 3rd, 4th, 5th).
5. The vehicle velocity and acceleration are calculated using the following equations for each gear ratio.

$$V = \frac{RPM \times \pi \times r}{30 \times n \times n_0 \times \eta_{tf}} \quad (2)$$

$$a = \frac{T \times n \times n_0 \times \eta_{tf}}{r \times m} - \frac{1}{m}\left[0.01 \times W\left(1 + \frac{V(Km/hr)}{160}\right) + W sin\theta + \frac{C_D \times A \times V^2(Km/hr)}{23.8}\right] \quad (3)$$

6. Calculate the maximum acceleration limit and maximum force using the following equations.

$$\Sigma R = \left[0.01 \times W\left(1 + \frac{V(Km/hr)}{160}\right) + W sin\theta + \frac{C_D \times A \times V^2(Km/hr)}{23.8}\right] \quad (4)$$

$$F_{max} = \frac{\mu mgb}{L - \mu h} \quad (5)$$

$$a_{max} = \frac{F_{max}}{m} \quad (6)$$

7. Calculate distance and time using the equations below.

$$x = \int_{V_{i-1}}^{V_i} \frac{mV^2}{746 \times HP} dV \quad (7)$$

$$t = \int_{x_{i-1}}^{x_i} \frac{1}{V} dx \quad (8)$$

8. After getting all the values, then we plot the distance-velocity curve, time-distance curve, time-velocity curve, velocity-acceleration curve, and any other curves for this manual transmission design.

The MATLAB code begins with vehicle parameters such as mass, gear ratios, wheel radius, slope, and data for torque and RPM. It reads the torque and RPM values from external Excel files, calculates acceleration and velocity, and plots the torque versus RPM. The pseudocode for this study is presented in Figure 2 below.

```
Clear workspace, command window, and close figures
Set vehicle mass m, gear ratios n, wheel radius r, and slope theta
Read torque data from 'torque_new.xlsx'
Read RPM data from 'RPM_new.xlsx'
Convert RPM to angular velocity omega using the formula ω = RPM * π / 30
Initialize acceleration matrix as a zero matrix with 61 rows and 5 columns
Initialize velocity matrix as a zero matrix with 61 rows and 5 columns
Plot torque vs RPM graph
Set axes labels: 'RPM' for x-axis and 'Torque (Nm)' for y-axis
Begin further calculations (not shown in code):
    Loop through gear ratios and calculate acceleration and velocity
    Update matrices for each gear based on torque and omega
    Plot graphs for acceleration and velocity against time
Return final performance results of vehicle transmission
```

Figure 2. Pseudocode for the present study

RESULTS AND DISCUSSION

The developed MATLAB code is used to design the transmission system with the following requirements: .Achieving a maximum vehicle speed of at least 160 km/h, maintaining a speed of 110 km/h on a 5% slope, Achieving acceleration to 120 km/h within 200 meters, and, if possible, a 0–100 km/h acceleration time of under 9 seconds. The vehicle parameters for this manual transmission design are described below.

- Front area *A*: 1.2 m x 1.8 m
- Drag coefficient C_D: 0.27
- Final drive ratio n_0 : 3.23
- Transmission efficiency η_{tf} : 0.9
- Gross Vehicle Weight Rating (GVWR) : 1935 kg
- Curb weight : 1415 kg
- Driver/passenger weight : 80 kg (2 persons)

- Tire code : 205/55 R 16 W
- Friction coefficient μ : 0.75
- Wheel base L : 2.76 m
- Height of CG h : 52 cm
- Center of gravity CG : 50% on the front axle
- RPM = 1000 to 7000

The procedure of the transmission design is as follows: Firstly, we set the ratio of the first gear to 3.62 so that its output force is close to the maximum traction force, and then we set the ratio of Gear 5 equal to 1, this ratio means that the engine and the transmission's output are moving at the same speed. The ratio between Gear 1 and Gear 5 is about 3.62, so the fixed ratio between the two gears ($3.62^{0.25}$) is about 1.38. Lastly, the gear ratio of Gear 2 - Gear 4 can be determined by the fixed ratio.

Table 1. The result of the gear ratio

Gerar	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5
Gear ratio	3.62	2.63	1.91	1.38	1.0

The first design requirement is the maximum speed of at least 160 km/hr. In order to evaluate this requirement, firstly we draw the constant HP curve using the equation below, where the maximum power is 160 kw.

$$F_{\text{constant HP}} = \frac{1000 \times 160}{V} \quad (9)$$

Then, the force limit value is calculated using the following equation.

$$F_{max} = \frac{\mu mgb}{L - \mu h} \quad (10)$$

For each slope, the resistance force curve is calculated using equation below.

$$R = 0.01 \times W\left(1 + \frac{V_{(km/hr)}}{160}\right) + W sin\theta + \frac{C_D \times A \times V_{(km/hr)}^2}{23.8} \quad (11)$$

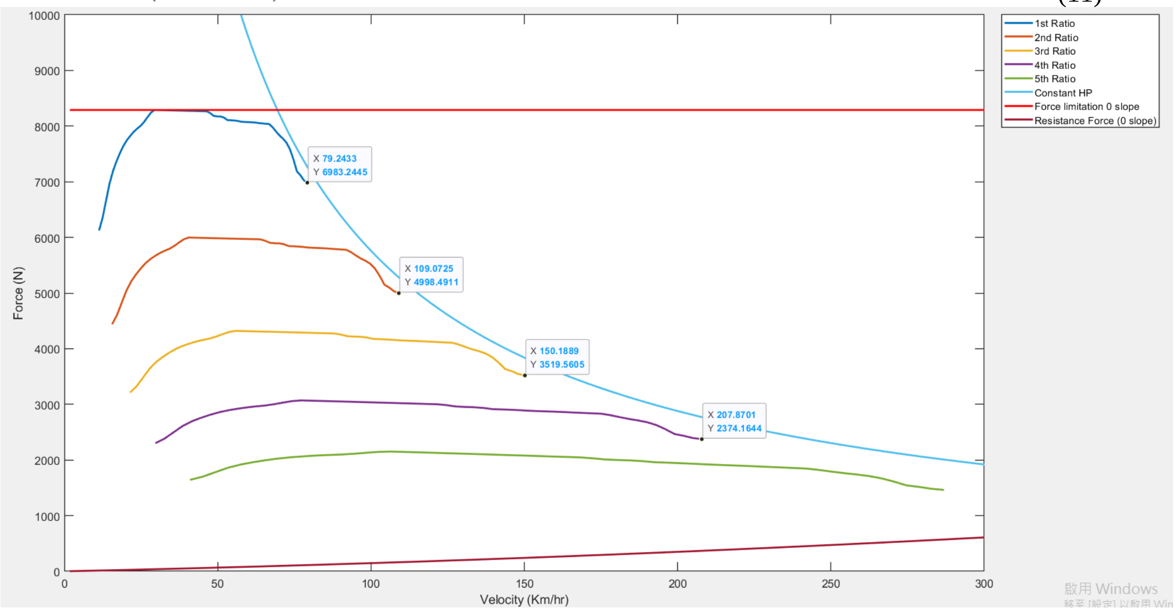

Figure 3. The velocity-force curve for each gear ratio.

Figure 3 illustrates the relationship between the force applied by the vehicle and its velocity across different gear ratios, from 1st to 5th gear. The curves demonstrate how the force changes as the vehicle accelerates through each gear. At low speeds, the 1st gear (blue curve) generates the highest force, around 8000 N, to help the vehicle start from a standstill. As speed increases, this force gradually decreases, and the vehicle transitions to higher gears, each providing progressively less force but allowing for higher speed. The 5th gear (green curve) enables the vehicle to reach a top speed of approximately 285 km/h, which is greater than typical design requirements.

Additionally, the graph includes lines for constant engine horsepower (cyan) and resistance force (brown), which highlight the factors affecting the vehicle's performance. The force limitation (red) represents the

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maximum force the vehicle can apply without exceeding the engine's capabilities. The transmission system is optimized so that in 1st gear, the force stays below this limit, ensuring efficient use of the engine's power. As the vehicle shifts to higher gears, the force applied decreases, improving fuel efficiency at higher speeds while still allowing for smooth acceleration.

The second design requirement is to maintain a speed of 110 km/hr on a 5 % slope in 5th gear (5 % slope = 2.86°). Figure 4 shows the velocity-force curve for a 5 % slope. When the vehicle velocity increases the resistance will also increase. This is because vehicle resistance is greatly influenced by its velocity, for example, aerodynamic resistance (equation 11). The resistance force at 110 km/hr is about 1105 N, but the output force of the vehicle in 5th gear at 110km/hr is 2065 N, therefore, the speed of 110km/hr can be maintained by this vehicle at 5% slope in 5th gear.

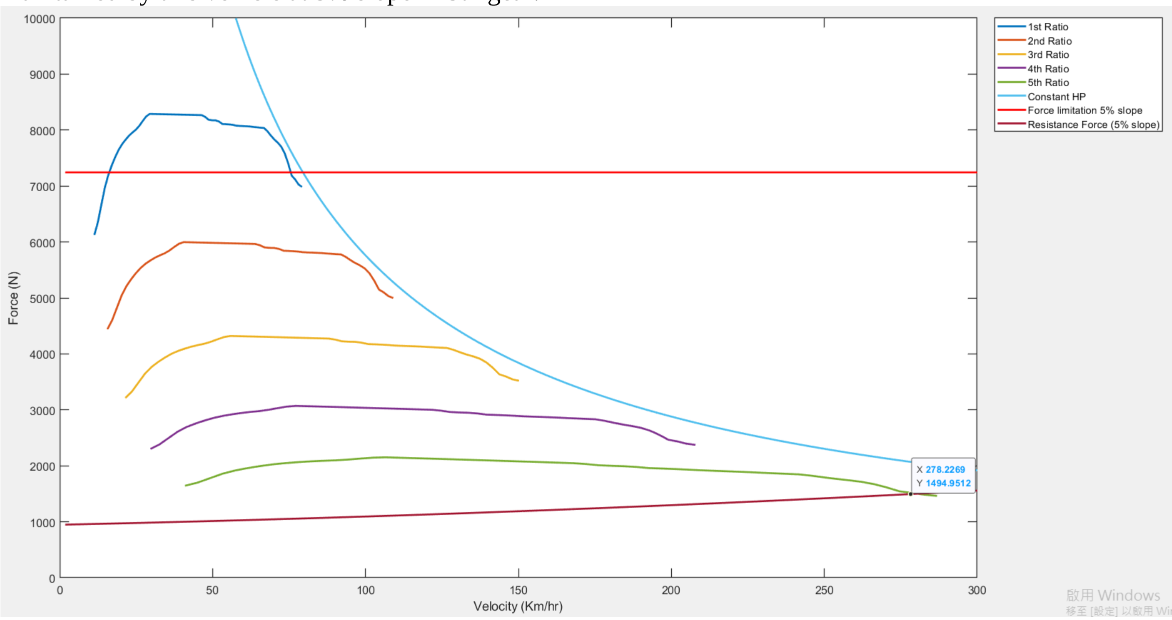

Figure 4. The velocity-force curve for a 5 % slope

The force limit value for a 5 % slope is calculated using the equation below.

$$F_{max} = \frac{1}{2}\mu mg\left(\cos\theta + \frac{h}{b}\sin\theta\right)$$

$$F_{max} = \frac{1}{2} \times 0.75 \times 1935 \times 9.81 \times \left(\cos 2.86 + \frac{0.52}{1.38}\sin 2.86\right) = 7243.24 \text{ N} \tag{12}$$

Based on the calculation of equation 12, the force limit is larger than the resistance force, so the vehicle can move forward. For each slope, the resistance force curve is calculated using Equation 11.

The third design requirement is achieving acceleration to 120 km/h within 200 meters, and, if possible, a 0–100 km/h acceleration time of under 9 seconds. Figure 5 shows the distance-velocity curve for acceleration performance design. As shown in Figure 5, the velocity of the vehicle when it runs 200 meters is about 124 km/hr. Figure 6 shows the time-velocity curve for acceleration performance design. As shown in Figure 6, it takes about 7.2 seconds for the vehicle to accelerate from 0 - 100 km/hr. Based on these results, we can conclude that the presented design can fulfill the third design requirement.

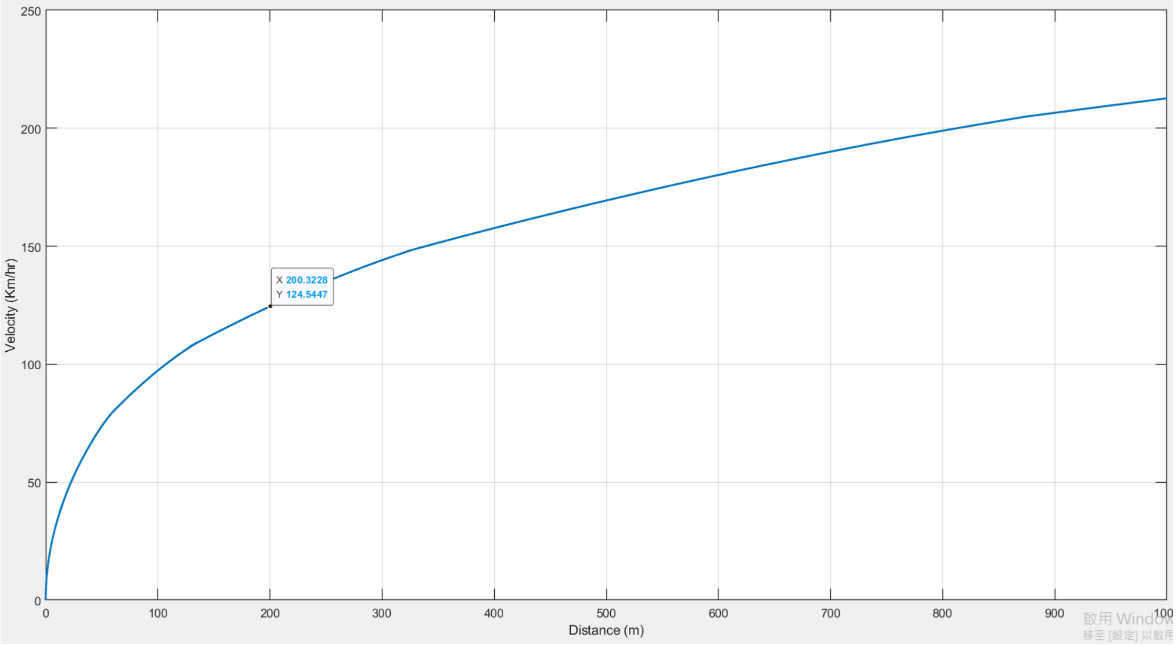

Figure 5. The distance-velocity curve for acceleration performance design

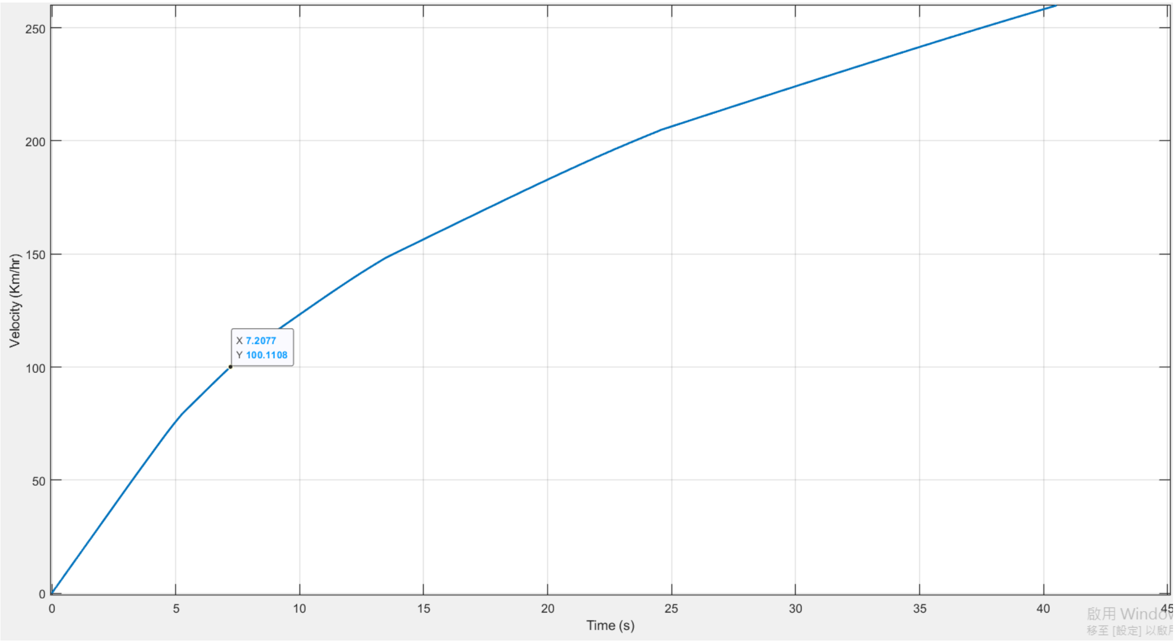

Figure 6. The time-velocity curve for acceleration performance design.

CONSLUSIONS

In this study, we successfully developed a MATLAB code to design and evaluate gear ratios for a vehicle transmission system, focusing on optimizing both acceleration and fuel efficiency. The MATLAB code is capable of calculating key vehicle performance metrics such as velocity, acceleration, and the forces exerted across different gear ratios. The design process also involved integrating various vehicle parameters, including torque, RPM, and resistance forces, ensuring that the vehicle's transmission system functions efficiently under different conditions, such as varying slopes and speeds.

The results of the tests conducted using the developed code demonstrate that the vehicle can meet critical performance benchmarks. For instance, the vehicle was able to reach a top speed of 285 km/h, exceeding the design requirement of 160 km/h, and could maintain a speed of 110 km/h on a 5% slope. Additionally, the acceleration performance was optimized, achieving a 0-100 km/h time of 7.2 seconds, which is better than the target of under 9 seconds. This indicates that the MATLAB code not only fulfills the design requirem

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