International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Intelligent Design of Six-Speed Gearbox: An AI Approach Using Python

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Abstract: ***This paper presents an innovative AI-enhanced integrated approach to the design of a six-speed constant mesh gearbox, utilizing CATIA software for the engineering design process and a Python-based calculator to evaluate vehicle speed based on various performance parameters. The primary objective of the study is to optimize vehicle performance by thoroughly examining the intricate interplay between critical factors such as gearbox design, tire size, road gradient, and final gear ratio. To achieve this, we begin by establishing a comprehensive framework that captures the essential elements of gearbox design. By employing CATIA, we create detailed 3D models that adhere to mechanical standards while allowing for iterative testing of different design configurations. Concurrently, we develop a Python-based computational tool that integrates real-time data inputs and allows for the simulation of vehicle performance under various conditions. The findings of this research illustrate the potential of combining advanced design tools and AI methodologies in the field of automotive engineering. The results demonstrate significant improvements in design efficiency and vehicle performance compared to traditional approaches, underscoring the importance of integrating computational intelligence into the engineering design process. This work not only contributes to more effective gearbox design but also sets a foundation for future innovations in automotive technology, promoting the development of smarter, more efficient vehicles.***

Keywords: AI in mechanical engineering; Gearbox design; CAD; Python programming; Automotive

1. Introduction

A device to change the torque and speed between the engine and the driving wheels is necessary for all automobiles. Although torque cannot be directly changed, it can be economically and effectively turned into power by utilizing the right tool. The goal of this project is to develop and build a gearbox that maximizes torque transmission and makes power transfer in automobiles easier. In order to attain the required torque and speed output, the system uses two shafts and thirteen gears that are positioned strategically over six speeds [1]. An output shaft receives speed and torque from a rotating power source through the use of a gearbox, a mechanical mechanism that inversely proportions the two quantities. Multi-speed gearboxes use the meshing of teeth to transmit motion and power in applications that require frequent modifications to speed and torque. To accomplish particular speed ratios, several gears are attached; popular varieties include sliding mesh, constant mesh, and synchromesh gearboxes. Sliding gears in sliding mesh gearboxes can engage with different stationary gears by moving along splined shafts [2]. Because material choice has a big impact on overall prices, it is essential in gearbox design. Even though there are a lot of inexpensive alloys available, the best material for each gearbox component must balance performance and weight. It was decided to utilize one material for all shafts, one for the gears, and one for the casing in order to simplify the design process and reduce material variation [3]. Although the gearbox casing keeps the fluid integrity and safeguards the interior components, car manufacturers are very concerned about noise and vibration-related gearbox failure. This study investigates the vibration characteristics of a two-wheeler gearbox casing that has been improved by rib additions using finite element analysis. The natural frequencies of the CATIA-designed and NASTRAN-analysed system range from 857.3 Hz to 4726 Hz. It is essential to comprehend these frequencies in order to avoid resonance and possible fractures brought on by corresponding external excitations. The findings emphasize how crucial vibration mitigation is to maintaining the gearbox casing's dependability [4]. Six-speed constant mesh gearbox design Al 7075 is used in gearbox applications for helical gears because of its superior strength-to-weight ratio and good fatigue resistance, which make it ideal for handling high torque loads. The helical gear arrangement reduces noise and vibrations and guarantees quieter, more seamless operation. The gearbox's six gears offer a broad variety of gear ratios for the best engine performance at different vehicle speeds, and its constant mesh construction facilitates smooth and rapid gear shifts, improving the driving experience overall and cutting down on power losses [5]. In CATIA V5, a graphical user interface (GUI) and macros can be used to customize a two-stage spur gearbox design. Basic specs are entered by users, and the system uses formulas to determine other design parameters. The gearbox's part model is then created using these parameters, improving usability and efficiency [6] [7]. Torque transfer via gears or gear trains from a rotating power source to another device, with a focus on gearboxes for speed and torque conversion. For situations where speed or torque variations are required often, multispeed gearboxes are crucial in delivering the required output. Through the meshing of gear teeth, motion and power are transmitted. Two gearbox designs, modal analysis, and an assessment of the structural strength of each design are all included in the study. SOLIDWORKS is used to generate gearbox assemblies, while ANSYS is used to analyze the IGS files. Deformation affects gear efficiency, and the findings show that maximum stresses and deformations stay within allowable bounds [8] through [10] and [11].

When a researcher is unfamiliar with gear boxes, the basic design of an industrial gearbox can help them lay out a dependable working design. Additionally, it is meant for the reader to apply his own knowledge when choosing gearbox and component formulas, stress values, etc. [12]. A multispeed multistage gearbox is used when quick changes in torque or speed at the output are required. The goal of this study is to build a cost-effective, 4-speed, 2-stage gearbox that uses spur gears in order to achieve excellent transmission efficiency. For every component, stress-strain analysis and CAD plots have been made [13] through [15].

Particularly with regard to machine learning and AI advancements, there are numerous opportunities to improve the design process and aid in the solution of the inverse problem. Two major impediments to the development of gear transmissions are the electrification of vehicle powertrains and the anticipated scarcity of skilled engineers. The idea is to further automate the design process in order to provide flexible and optimal design solutions even with fast changing limitations and requirements, as traditional approaches reach their limits. As a result, we examine the existing design procedure, examine cutting-edge techniques for automated gear transmission design, and assess both their promise and the difficulties associated with combining machine learning techniques. Nevertheless, the field of gear transmissions has only published a small number of techniques to date. They give an object-oriented design formulation's attributes and interactions for each component. A decision tree and rule database are utilized to generate topology solutions in an exhaustive graph. Shafts, gearsets, clutches, shifting elements, and power inputs and outputs are among its constituents [18]. Artificial intelligence provides a whole new perspective for working in the design process, allowing for the creation of intelligent systems for automated design—in this example, the design of gear power transmitters. Conventional and Intelligent systems are the two sorts of automated design systems that can be activated. The fact that traditional automated design systems rely on CAD, CAM, and CAE technology is one of their distinguishing features. The data organization they allude to is a traditional one, typically involving hierarchical or network database models or the architectures of unique (graphical) data files. The support for software is procedural [19].

In the field of mechanical engineering, gear design calculations are known to be time-consuming and to involve numerous terminologies, parameters, and principles that create complex boundary conditions. However, with the aid of Python programming, we can quickly resolve such problems by building our own Python libraries [18]. The current work employs CATIA for part modeling and focuses on designing a six-speed constant mesh gearbox. Using standard methods, the RPM values for the six gears (N1, N2, N3, N4, N5, N6) have been determined. Three different Python programs have been created by utilizing these RPM numbers in conjunction with vehicle factors including tire size, final drive ratio, and road gradient. These programs make it easier to calculate the vehicle speed for each gear (1-6) and for all RPM values (N1-N6). Compared to conventional methods, we achieve significant time savings for speed computations by using this AI-driven approach. By altering the gear settings while keeping a steady RPM, the vehicle's speed is determined. On the other hand, speed can also be determined by varying the RPM while maintaining the same gear. Conversely, speed is also assessed by keeping the gear constant and adjusting the RPM values. This dual approach allows for a comprehensive analysis of vehicle performance across different operating conditions.

2. Methodology

Work is divided into four different sections as following

Gearbox Design Overview
- Description of the gearbox design requirements and objectives.
- Overview of the constant mesh mechanism and its advantages.

CAD Modeling
- Step-by-step process of creating the gearbox components in CAD software (e.g., CATIA).
- RPM Calculation by traditional method.

Vehicle Speed Calculation
- Introduction to the parameters influencing vehicle speed (RPM, tire size, gear ratios).
- Development of the Python program for speed calculations.

2.1 Gearbox Design Overview

Design Requirements and Objectives: The gearbox design focuses on creating a six-speed constant mesh system that meets specific performance criteria, such as optimizing power transfer, enhancing fuel efficiency, and ensuring smooth shifting. Key objectives include minimizing weight while maximizing strength, durability, and ease of maintenance, ensuring that the gearbox can handle varying driving conditions effectively.

Constant Mesh Mechanism: The constant mesh gearbox employs a design where all gears are engaged at all times, allowing for seamless shifting between gears without disengaging the engine. This mechanism offers several advantages, including reduced wear on components, improved torque delivery, and enhanced responsiveness during gear changes. The design promotes efficiency and reliability, making it ideal for high-performance applications where precise control over power output is essential.

2.2 CAD Modeling

In this, we have done Design and drafting of Gearbox by CATIA V5 Software.

a) Gearbox Housing

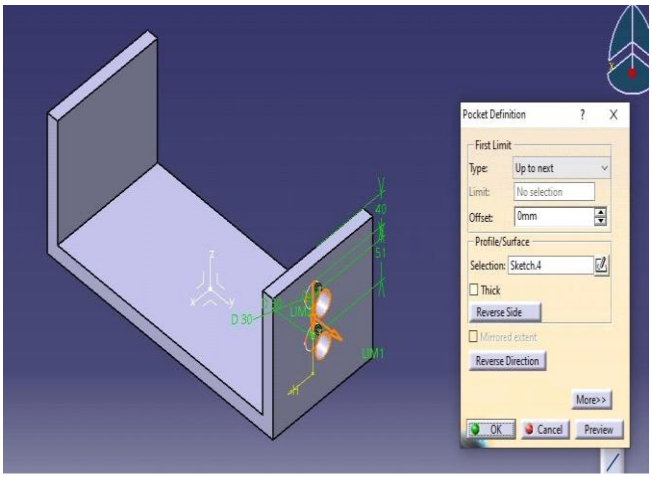

Figure 1: Gearbox housing model.

Paper ID: SR25529111139 DOI: https://dx.doi.org/10.21275/SR25529111139

The CAD model of the gearbox housing is designed to provide structural integrity and protection for internal components. Key design features include an optimized shape, lightweight materials, strategic mounting points, and ventilation systems for effective cooling. The modeling process involves utilizing CAD's capabilities through steps like sketching, extrusion, and filleting, with an emphasis on parametric design for flexibility and precision. To ensure performance under operational conditions, stress and thermal simulations were conducted, validating the design's robustness. The final presentation highlights the model from various views, emphasizing its critical role in prototyping and integration into vehicle systems.

b) Gear

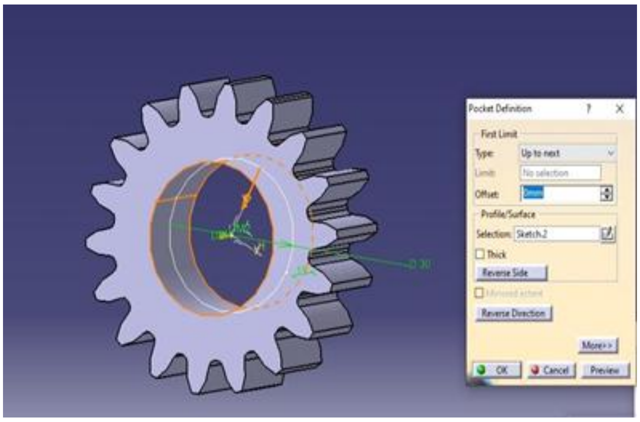

Figure 2: Gear model

The CAD model of the gear in a constant mesh gearbox is crucial for understanding the transmission system's functionality. This model features precisely designed teeth profiles that ensure smooth engagement and disengagement while minimizing wear and noise. The modelling process involves creating detailed sketches of the gear's geometry, followed by extrusion and refinement to achieve the desired specifications

c) Shaft

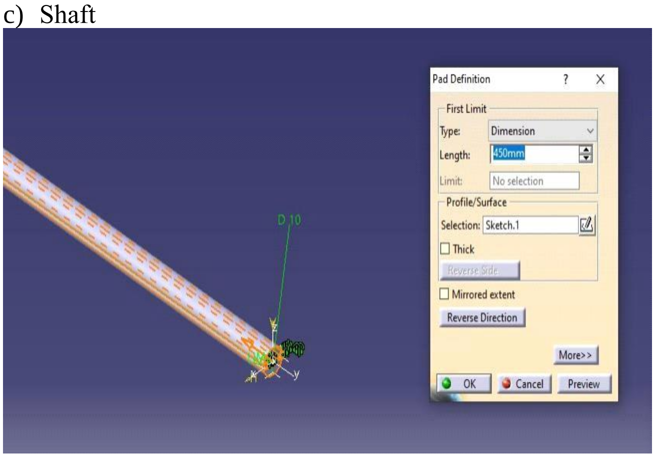

Figure 3: Shaft model

The CAD model of the shaft in a constant mesh gearbox design plays a vital role in the overall functionality and efficiency of the transmission system. This model is crafted to specific dimensional tolerances to ensure a precise fit within the gearbox assembly. The design process involves creating a detailed representation of the shaft's geometry, including its length, diameter, and keyway features for secure gear attachment. The shaft's material properties are also defined to ensure it can withstand the operational stresses and torque loads encountered during vehicle operation.

d) Gearbox assembly

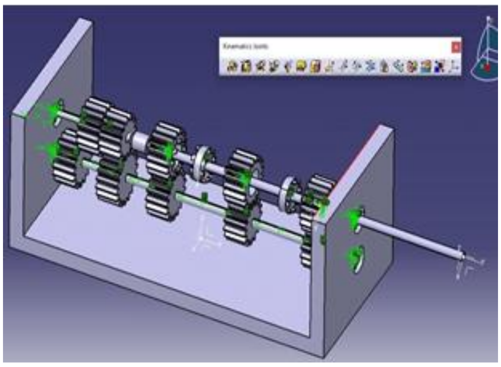

Figure 4: Gearbox assembly.

The CAD model of the gearbox assembly in a six-speed constant mesh gearbox design serves to illustrate the critical components and their interactions in power transmission. It includes key elements such as input and output gears, main and counter shafts, and the protective housing. The model highlights the constant mesh mechanism, ensuring smooth gear engagement without synchronizers. The assembly process is meticulously detailed, showing the precise alignment and spacing of gears on the shafts. Additionally, the CAD model incorporates simulation capabilities for motion and stress analysis, verifying performance under load. Visual aids, such as rendered images and section views, enhance understanding of the internal workings. Overall, this CAD model streamlines the design process, facilitating iterative improvements and ensuring the reliability and efficiency of the gearbox.

e) Orthographic view of gear box

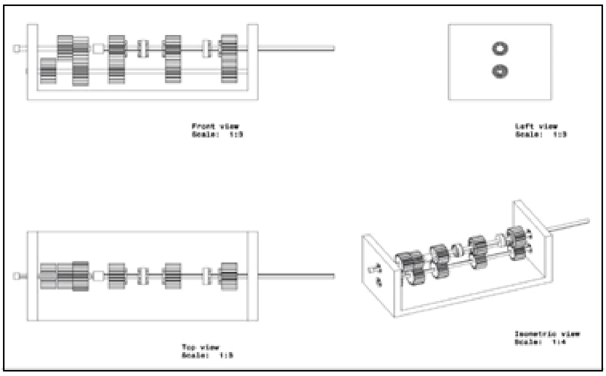

Figure 5: Orthographic view of gearbox

The orthographic view of the constant mesh gearbox provides a detailed representation from multiple perspectives—typically front, top, and side views—highlighting the dimensions and spatial relationships of critical components such as the input and output shafts, gears, and housing. This view aids in precise measurements and emphasizes key design aspects, ensuring proper alignment and assembly. Annotations for dimensions and materials enhance clarity, making it an essential communication tool for stakeholders, facilitating manufacturing, assembly, and future modifications while allowing for the identification of potential design flaws early in the process.

2.3 RPM Calculation by traditional method.

Specification of motor

- Power (P) = 3 KW
- Maximum speed (Nmax) = 3000 RPM
- Minimum speed (Nmin) = 2000 RPM

Torque

$$P = \frac{2\pi NT}{60 \times 1000}$$

$$T = \frac{P \times 60 \times 1000}{2\pi N}$$

Torque (T) = 9.54 N.m

Speed Ratio (Rn)

$$Rn = \frac{Nmax}{Nmin} = \frac{3000}{2000}$$

Speed Ratio (Rn) = 1.5

$$\Phi = \mathrm{Rn}^{\frac{1}{z-1}}$$

$$\Phi = 1.5^{\frac{1}{6-1}}$$

$$\Phi = 1.08$$

$$3000 = a(\varphi)^{z-1}$$

$$3000 = a(1.08)^{6-1}$$

$$\mathrm{a} = \frac{3000}{1.08^5} = 2041.74 \text{ RPM}$$

a=2042 RPM

By using the same process,

$$\text{2nd Speed} = \mathrm{a} \times \varphi^1$$
$$= 2042 \times 1.08^1 = 2205 \text{ RPM}$$

$$3\text{rd } Speed = a \times \varphi^2$$
$$= 2042 \times 1.08^2 = 2382\ RPM$$

$$4\text{th } Speed = a \times \varphi^3$$
$$= 2042 \times 1.08^3 = 2578 \text{ RPM}$$

$$5\text{th } Speed = a \times \varphi^4$$
$$= 2042 \times 1.08^4 = 2778\ RPM$$

$$6\text{th } Speed = a \times \varphi^5$$
$$= 2042 \times 1.08^5 = 3000 \text{ RPM}$$

Table 1: Gear Speed

Speeds	Value in RPM
N1	2042 RPM
N2	2205 RPM
N3	2382 RPM
N4	2578 RPM
N5	2778 RPM
N6	3000 RPM

2.4. Vehicle Speed Calculation

Introduction to the parameters influencing vehicle speed-

- Vehicle speed is influenced by key parameters: RPM (Revolutions Per Minute), tire size, and gear ratios.
- RPM indicates engine speed, directly impacting power and torque. Higher RPMs typically increase power but can reduce fuel efficiency and increase engine wear.
- Tire size affects the distance traveled per wheel rotation; larger tires enhance top speed but may limit acceleration, while smaller tires improve acceleration but can restrict maximum speed.
- Gear ratios establish the relationship between engine and wheel speeds. Lower ratios provide better torque for acceleration, while higher ratios optimize speed and fuel efficiency on highways.
- Development of the Python program for speed calculations.

Three different python programs have developed for vehicle speed calculation by considering different parameters.

2.4.1 Vehicle Speed based on RPM (revolutions per minute) and Tire Size.

Program Logic –

The implementation involves several key components: a list of gear ratios, a fixed tire circumference representing tire size, and a function to calculate speed. This function accepts RPM and gear as inputs, verifies the validity of the gear, and computes speed based on the gear ratio, converting the result to km/h. The main logic prompts the user for RPM and gear number (1 to 6), calls the calculation function, and prints the resulting speed. This code can be executed in any Python environment, allowing users to easily input RPM and gear to obtain the calculated speed.

2.4.2 Vehicle Speed calculation based on Final Drive Ratio along with Gear Ratios

Instead of using tire circumference, we can incorporate another parameter such as the final drive ratio. Here's the modified version of the program that uses final drive ratio along with gear ratios.

Program Logic –

The implementation includes key components: a list of gear ratios for each gear and a fixed final drive ratio representing the vehicle's overall drive configuration. A function, calculate speed, takes RPM and gear as inputs, verifies the gear's validity, and computes speed using a formula that incorporates both the gear ratio and the final drive ratio.

The main logic prompts the user for RPM and gear number (1 to 6), then invokes the calculate speed function to derive the speed. The result is displayed in kilometers per hour (km/h). This code can be executed in any Python environment, allowing users to input RPM and gear number, resulting in an immediate calculation of vehicle speed based on the defined ratios.

2.4.3 Vehicle Speed calculation based on Road Gradient

Let's use a different parameter such as road gradient to affect the speed calculation. The road gradient can impact the effective speed based on the incline or decline of the road. Here's the modified program that incorporates road gradient.

Program Logic –

Python code calculates vehicle speed based on engine RPM, selected gear, and road gradient. It begins by defining a list of gear ratios for a six-speed gearbox. The calculate speed function takes three parameters: RPM, gear, and road gradient. It first checks if the gear is valid (between 1 and 6) and retrieves the corresponding gear ratio. The base speed is calculated in meters per minute using a formula that incorporates RPM and the gear ratio, applying a constant factor for speed estimation. The function then adjusts this base speed according to the road gradient, which is expressed as a percentage, modifying speed for uphill and downhill scenarios. The final speed is converted from meters per minute to kilometers per hour. The main logic prompts the user for input values and calls the calculate speed function, displaying the calculated speed. Error handling is included to ensure that only valid numeric inputs are accepted, enhancing user experience.

3. Result and Discussion

3.1 Vehicle speed based on different parameters

Table 2: Results for Vehicle speed

Sr. No	Gear No.	RPM	Vehicle Speed (Based on RPM and Tire Size)	Vehicle Speed (Based On RPM and Final Drive Ratio)	Vehicle Speed (Based On RPM and Road Gradient)
1	1	2042	76.58	18.68	68.92
2	2	2205	142.48	34.75	128.23
3	3	2382	229.11	55.88	206.20
4	4	2572	324.07	79.04	291.66
5	5	2778	473.01	115.37	425.71
6	6	3000	756.00	184.39	680.40

Table 2 shows the results for vehicle speed based on different parameters. As gear number increases from 1 to 6, RPM rises, indicating that higher gears facilitate maintaining higher speeds, typical for vehicle operation where lower gears are for acceleration and higher gears for cruising. The calculated speeds based on tire size are significantly higher than those derived from final drive ratio and road gradient, suggesting that tire size is less of a limiting factor in real-world conditions. This highlights that while RPM can indicate potential speed, practical speeds are influenced more by gearing and external factors. Understanding these speed dynamics is essential for optimizing performance, fuel efficiency, and safe driving, as actual vehicle speed depends on a combination of gearing, engine power band, and road conditions.

3.2 Vehicle performance Analysis

a) Effect on vehicle speed when Constant RPM at Different Gears

Table 3: Results for vehicle speed when Constant RPM at Different Gears

S. No	Gear No.	RPM	Vehicle Speed (Based on RPM and Tire Size)	Vehicle Speed (Based On RPM and Final Drive Ratio)	Vehicle Speed (Based on RPM and Road Gradient)
1	1	2042	76.58	18.68	68.92
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4	4	2572	324.07	79.04	291.66
5	5	2778	473.01	115.37	425.71
6	6	3000	756.00	184.39	680.40

Table 3 shows, As the gear number increases from 1 to 6, vehicle speeds based on all three calculations show significant increases. Lower gears (1-3) provide lower speeds but are better suited for acceleration and pulling power, making them ideal for starting and low-speed driving conditions. In contrast, higher gears (4-6) enable the vehicle to achieve greater speeds, optimizing efficiency for cruising on highways. This shift in speed illustrates how gear selection plays a crucial role in balancing performance and efficiency under different driving scenarios. The significant differences in vehicle speeds calculated based on road gradient illustrate that external factors like terrain can greatly affect performance. For instance, a steeper gradient might require more power to maintain speed, thereby affecting the vehicle's actual speed performance compared to ideal conditions.

b) Effect on vehicle speed when Varying RPM at a Fixed Gear

Table 3: Results for vehicle speed when varying RPM at a Fixed Gear

S. No.	Gear No.	RPM	Vehicle Speed (Based on RPM And Tire Size)	Vehicle Speed (Based On RPM And Final Drive Ratio)	Vehicle Speed (Based On RPM And Road Gradient)
1	1	2042	76.28	8.89	328.18
2	1	2205	82.69	9.60	354.38
3	1	2382	89.33	10.37	382.82
4	1	2572	96.45	11.20	413.36
5	1	2778	104.18	12.10	2027.19
6	1	3000	112.50	13.07	3240.00

The data demonstrates how vehicle speed varies at different RPM values while in the same gear (1) across various speed calculations. As RPM increases from 2042 to 3000, vehicle speed consistently rises in all three categories—based on tire size, final drive ratio, and road gradient. This trend reflects the direct relationship between RPM and speed; as the engine works harder, the vehicle can move faster, even in the same gear. The speeds calculated based on tire size provide an idealized maximum speed, while those based on final drive ratio offer a more practical reflection of real-world performance, illustrating how gear ratios and driveline factors impact speed. Notably, the significantly higher speeds associated with road gradient indicate that terrain greatly influences a vehicle's potential, underscoring the importance

Paper ID: SR25529111139 DOI: https://dx.doi.org/10.21275/SR25529111139

of context in performance assessments. Overall, these results highlight RPM as a key factor in vehicle speed and emphasize the influence of external conditions, gear ratios, and tire specifications on overall performance.

4. Conclusion

This research demonstrates the significant advancements possible in the design of six-speed constant mesh gearboxes through an integrated AI-enhanced approach. By leveraging CATIA for detailed 3D modelling and developing a Python-based calculator for vehicle speed evaluation, we have effectively optimized vehicle performance by examining the complex interactions between gearbox design, tire size, final drive ratio, and road gradient. The findings reveal that combining advanced design tools with computational intelligence leads to enhanced design efficiency and improved vehicle performance compared to traditional methods.

The developed Python programs effectively illustrate how key parameters—such as tire size, final drive ratio, engine displacement, and road gradient—impact vehicle speed calculations. This understanding is crucial for automotive engineers seeking to optimize performance and enhance the driving experience. Although the calculator serves as a valuable tool, it does have limitations, such as the exclusion of factors like wind resistance and traction, which warrant further exploration in future studies. Overall, this research not only contributes to more effective gearbox design but also paves the way for future innovations in automotive technology, supporting the development of smarter, more efficient vehicles.

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