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Engineering Design and Performance Evaluation of a Transmission System for the UG 24 Urban Energy Vehicle

Muhammad Farid Riyanto[1], Juni Noor Rohman[2], Sutiman[3*]

[1]Department of Mechanical and Automotive Engineering, Faculty of Vocational, Universitas Negeri Yogyakarta, Kulon Progo, Yogyakarta 55652, Indonesia
[2]Graduate Program Student Mechanical Engineering, Wrocław University of Science and Technology, Poland
[3]Department of Automotive Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta, Sleman, Yogyakarta 55281, Indonesia

*Corresponding author: sutiman@uny.ac.id

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ABSTRACT

The development of energy-efficient vehicles in student competitions encourages innovation in lightweight and high-performance automotive systems. The Garuda UNY Team, representing Universitas Negeri Yogyakarta, has been actively involved in national competitions such as the Kontes Mobil Hemat Energi (KMHE). In recent evaluations, the team identified a critical weakness in their vehicle's drivetrain, specifically the Internal Gear Hub (IGH) used in the UG-24, which failed to withstand engine torque during acceleration, leading to gear slippage and mechanical failure. To address this issue, a new transmission system was designed and manufactured using the 4D development framework: Define, Design, Develop, and Disseminate. The Define phase identified the mismatch between the IGH design and engine torque requirements. In the Design phase, a new gearbox layout was modeled using Autodesk Inventor, incorporating components such as a crankcase, cover, and custom gear ratios. The development phase involved selecting materials, laser cutting, machining, and assembling transmission parts from mild steel and aluminum. Finally, the Dissemination phase consisted of installing the system in the UG-24 vehicle and conducting a performance evaluation through structured interviews with drivers. Evaluation results showed improved gear shifting performance, with a 75% success rate across ten indicators. Despite positive outcomes, some issues, such as shifting resistance and gear engagement noise, were observed. These were linked to cable friction and dog clutch geometry. Design improvements such as optimized routing and chamfering were recommended for future iterations. This research highlights the impact of tailored transmission systems in student-built energy-efficient vehicles. It provides insight into practical, scalable drivetrain solutions.

1. Introduction

Student organizations play a crucial role in fostering students' interests and talents across various disciplines, including science and technology [1]. At Universitas Negeri Yogyakarta (UNY), one of the most prominent organizations in engineering development is the Technology Engineering Student Organization (UKM Restek), which houses several divisions, including the Garuda UNY Team. This team focuses on research and development in the field of fuel-efficient and high-performance vehicles, applying engineering principles and knowledge gained during the academic process. Over the years, the Garuda UNY Team has actively participated in both national and international competitions such as the Shell Eco-marathon, Student Formula Japan, and the Energy Efficient Car Contest (KMHE), a highly competitive annual event in Indonesia [2].

In participating in the KMHE competition, the Garuda UNY Team has encountered various technical challenges that hindered its ability to achieve the targeted fuel efficiency of 700 km/liter. Based on internal evaluations, several key factors were identified: aerodynamic drag resulting from the body design, excessive friction in the braking system, chassis deflection due to uneven load distribution, and transmission system failure caused by an inability to handle engine torque [3, 4]. Notably, the Internal Gear Hub (IGH) transmission system, initially designed for bicycles, proved to be inadequate for use in an urban concept vehicle due to its inability to transfer power under high-torque conditions [5] efficiently.

From an engineering perspective, the failure of the IGH transmission system highlights a mismatch between component specifications and the vehicle's torque requirements. A transmission not designed to handle high torque and dynamic loads is prone to deformation or mechanical failure [5]. Furthermore, suboptimal gear ratios negatively affect acceleration and energy efficiency [6]. Previous studies recommend that energy-efficient vehicle transmissions should be designed to maximize torque transfer efficiency, minimize internal friction, and utilize lightweight yet robust materials and structures [7, 8].

This issue is further exacerbated by spatial limitations within the urban vehicle's chassis, which demands a compact and precisely integrated transmission system. Key factors, such as material selection, housing design, and assembly techniques, must be carefully considered to avoid new issues, including vibration or misalignment of the drivetrain [7, 9]. Without a well-engineered design, even newly developed systems may compromise driving performance or comfort. Therefore, a systematic engineering approach is required to develop a new transmission system that ensures optimal power transfer, structural reliability, and spatial efficiency.

To address these challenges, this study proposes the design and fabrication of a custom transmission system tailored specifically to the needs of the Garuda UNY Team's urban vehicle. The proposed system is developed based on real torque requirements, spatial constraints, and operational ergonomics. It is expected that this new design with improved structural strength, precision, and optimal gear ratios will significantly enhance both vehicle acceleration and energy efficiency. This research not only aims to provide a technical solution for the team's current limitations but also contributes to the broader field of sustainable mobility and energy-efficient vehicle development in Indonesia.

2. Methodology

2.1 Design Procedure

This study employs a Research and Development (R&D) approach combined with the 4D model development stages: Define, Design, Develop, and Disseminate [10]. At the Define stage, the research team identified the critical problem in the UG 24 vehicle, specifically the inability of the Internal Gear Hub (IGH) transmission to withstand the high engine torque, which caused frequent system failures. Recognizing this limitation became the basis for developing a new, more robust transmission system to enhance the vehicle's acceleration performance.

During the Design stage, the transmission system components were modeled using the SolidWorks software. The design focused on several key parts, including the Crankcase, Crankcase cover, Input and output gears, Shift drum, Shift forks, and Bushing bearings. The design aimed to optimize space constraints within the urban vehicle chassis, ensuring precise gear meshing to reduce backlash and improve transmission efficiency. To determine the appropriate gear ratios for each transmission stage, Equation 1 was used to calculate the maximum velocity based on wheel diameter and gear ratio.

$$v = \frac{\pi \cdot D_w \cdot 60 \cdot RPM}{1000 \cdot r_{total}} \quad (1)$$

Where : v = Average speed
D_w = Wheel diameter
r_{tot} = Total gear ratio

At the Development stage, the transmission components were custom-manufactured in a workshop setting. Processes such as laser cutting for crankcase fabrication, turning for bushing bearing creation, and milling for precision adjustments were employed to bring the design to life. The manufacturing process prioritized the use of lightweight yet durable materials to enhance the overall vehicle performance while maintaining structural integrity.

Finally, the Disseminate stage involved functional testing and evaluation of the developed transmission. Road tests were conducted alongside interviews with the drivers to gather qualitative feedback on the ease of gear shifting, operational smoothness, and ergonomic considerations of the gear shifter. This stage ensured that the transmission system met performance expectations and could be effectively integrated into future competition vehicles.

3. Result and Discussion

3.1 Final product design

Fig. 1 shows the final design of the transmission. The transmission system developed in this study utilized a combination of materials selected for their mechanical strength, durability, and lightweight properties, thereby optimizing vehicle performance. The crankcase (Fig. 2) was fabricated from mild steel sheets with a thickness of 4 mm, chosen for its balance between strength and weight, ensuring robust protection for internal components while minimizing additional mass. The transmission gears, including input, output, and intermediate gears, were manufactured from alloy steel known for its high tensile strength and wear resistance, which is essential for withstanding the high torque loads during acceleration.

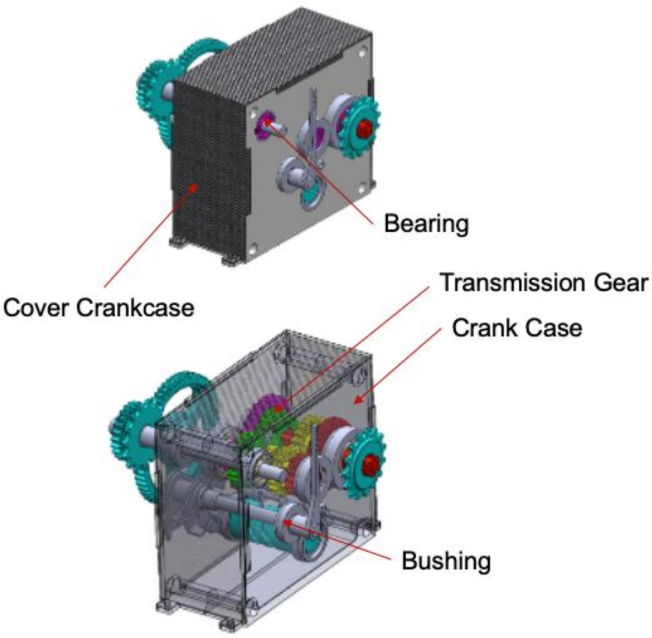

Figure 1. 3D design of transmission

Bearings and bushings were incorporated to reduce friction between rotating parts and maintain precise alignment of gear shafts [11]. Specifically, bronze bushings were chosen for their excellent load-bearing capacity and self-lubricating properties. At the same time, ball bearings made of hardened steel were selected for their ability to sustain both radial and axial loads. The assembly process involved precise machining to ensure tight tolerances, reducing backlash and improving the efficiency of power transmission.

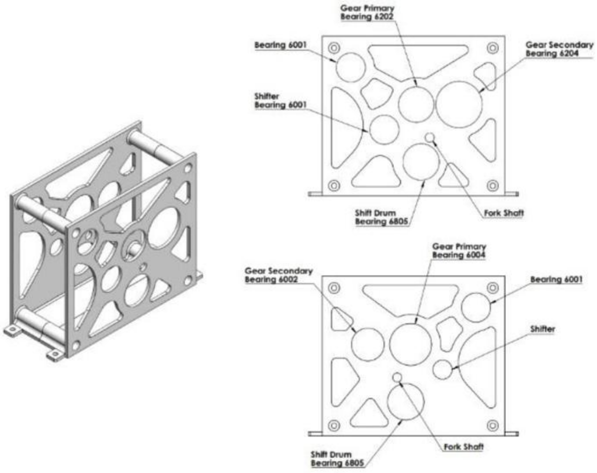

Figure 2. 3D design of crankcase component

The setup phase involved assembling all components within the limited space of the urban vehicle chassis. Special attention was given to the alignment of the crankcase and mounting points to ensure a secure fit within the vehicle frame, without compromising space or interfering with other systems. The gear-shifting mechanism, including the shift drum and forks, was calibrated to ensure smooth and accurate gear transitions [12]. Autodesk Inventor software was extensively used throughout the design and assembly process to simulate component fit and movement, thereby minimizing errors before physical manufacturing and assembly.

3.2 Manufacturing and assembly process

The manufacturing stage marks a critical transition from design to realization, involving the fabrication of individual transmission components and their precise assembly into a functional system. All components were custom-manufactured according to the CAD model specifications, with a focus on optimizing spatial constraints and structural integrity for the Urban Concept vehicle.

Figure 3. The component of transmission

Fig. 3 illustrates the complete set of transmission parts after the fabrication process. Key components include the crankcase, gear sets, bushing units, shafts, and the transmission cover. These parts were produced using a combination of laser cutting and CNC machining techniques, with materials selected to balance strength and weight, primarily mild steel for structural frames and aluminum T7 for lighter housing components. Each part was subjected to dimensional inspection to ensure fit tolerance, especially for rotating components such as bearings and shafts.

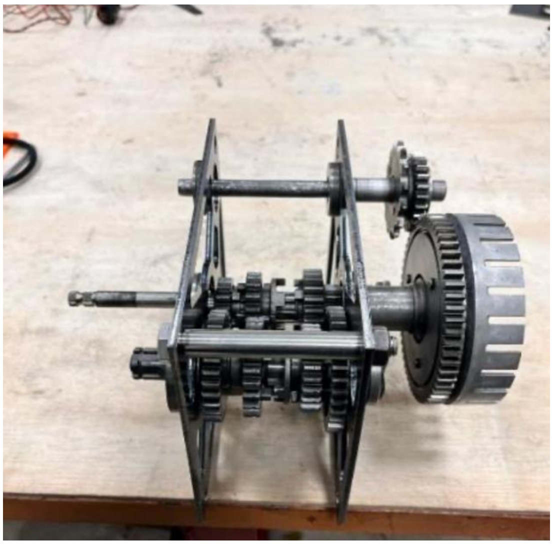

Figure 4. Assembly of transmission

Following fabrication, the assembly process was initiated. Fig. 4 shows the integration of all transmission components into a single unified system. This phase required high precision in aligning the input shaft, intermediate gears, and output shaft, as well as the installation of bushings and bearing seats. Proper alignment was critical to avoid backlash and ensure efficient torque transmission. Lubrication was applied to all contact surfaces to minimize friction during operation [13, 14].

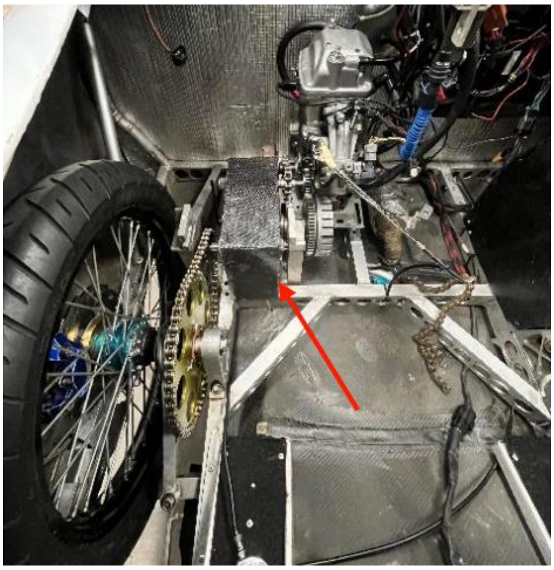

Figure 5. Installation of transmission on the chassis

Once assembled, the transmission unit was installed into the Urban Concept vehicle chassis, as shown in Fig. 5. The positioning of the transmission system was constrained by the existing IGH mounting space, which necessitated design adaptations to ensure compatibility. Special attention was given to the chain tension and alignment between the input gear and final drive [15]. The system was bolted securely to the vehicle frame, and a preliminary setting was conducted to check clearance and ensure smooth movement of the chain drive under load. This manufacturing and assembly workflow ensured that the final product was robust, functional, and tailored for real-world implementation on the Garuda UNY UG 24 vehicle. The success of this stage laid the groundwork for further testing and refinement in the performance evaluation phase.

3.3 Transmission system performance evaluation

The performance evaluation of the developed transmission system was conducted using a qualitative approach, involving a structured interview form. Two experienced drivers from the Garuda UNY Team were involved in the testing phase to assess the functionality and ergonomics of the transmission during actual vehicle operation. The evaluation focused on ten key indicators, including ease of gear shifting, gear engagement smoothness, the presence of unusual noises or jerking, and ergonomic factors such as gear lever accessibility and shifting effort.

Table 1. Evaluation result or the transmission

No.	Evaluation Criteria	Driver 1	Driver 2	Remarks
1	Ease of gear shifting	Yes	Yes	Gear shifting can be executed smoothly without excessive force.
2	Noise during acceleration	Yes	No	Noticeable gear noise is present
3	Shifting consistency across speeds	Yes	Yes	Smooth transition across all speed ranges, except minor resistance at higher speeds.
4	Presence of vibration or jerking	Yes	Yes	Slight jerking occurs during shifting due to the lack of a synchromesh system.
5	Transmission responsiveness during acceleration	Yes	Yes	Transmission remains responsive and consistent under acceleration.
6	Gear lever obstruction	Yes	Yes	The gear lever path is slightly obstructed due to suboptimal cable routing.
7	Accessibility of the gear lever	Yes	Yes	The lever position is ergonomically reachable and does not hinder operation.
8	Ease of returning to neutral	Yes	Yes	The neutral position is easily identifiable in all conditions.
9	Gear slippage	No	No	No slippage detected during normal operation.
10	The effort required for shifting	Yes	Yes	Gear shifting does not require excessive force; it operates within ergonomic limits.

Based on the structured form, each driver was asked to provide their feedback by answering "Yes" or "No" to each question, which was designed to reflect real-time driving conditions during acceleration, deceleration, and cruising. The criteria also addressed potential issues such as gear slippage and difficulties in returning to the neutral position.

From the initial feedback shown in Table 1, the drivers reported that the gear shifting process could generally be executed smoothly, with the gear lever easily reachable and operable without excessive force. However, both drivers noted the presence of a slight jerking sensation and a coarse sound when shifting from gear two to gear three. This issue is likely caused by the use of a constant mesh (non-synchronized) transmission system, which lacks a synchromesh mechanism to harmonize gear and shaft speeds prior to engagement.

Furthermore, minor resistance was observed in the gear lever's movement, particularly due to the suboptimal routing of the cable mechanism, which resulted in increased friction. This suggests a need for future optimization in the cable arrangement and selection of more flexible materials to enhance responsiveness and user comfort [16]. In general, the evaluation showed that 75% of the performance indicators were met satisfactorily, indicating that the developed transmission system functions effectively and is suitable for use in competition.

Nonetheless, several areas have been identified for improvement, including the refinement of gear engagement surfaces and the enhancement of cable mechanism ergonomics.

3.4 Weakness analysis and improvement

Based on the evaluation results and observations during the transmission testing phase, several weaknesses were identified in the newly developed transmission system. These weaknesses are important to analyze in order to provide constructive insights for future improvements. The first noticeable issue was the presence of harsh noise and vibration, particularly when shifting from the second to the third gear. This symptom is indicative of impact engagement caused by the non-synchronized nature of the constant mesh transmission. Without a synchromesh mechanism, the gear and shaft rotations are not equalized before engagement, resulting in abrupt contact [17]. This condition leads to discomfort and potential long-term mechanical wear. To address this issue, a redesign of the dog clutch geometry is proposed, incorporating chamfering or tapering on the gear teeth. This technique smoothens the engagement process by allowing gradual contact between gear teeth, thereby reducing the impact force and enhancing shifting comfort.

Another observed weakness involves the gear shifter cable system. During testing, the shift lever occasionally exhibited resistance, which disrupted the smoothness of gear changes. This problem is attributed to suboptimal routing of the cable and excessive curvature, which increases friction and hampers responsiveness. Improvement can be achieved by optimizing the cable routing layout, minimizing unnecessary bends, and possibly using more flexible or low-friction cable materials. Additionally, fine-tuning the cable tension is recommended to align with ergonomic standards and enhance user control during shifting [18].

Furthermore, it was noted that the manufacturing tolerances of the bushing and bearing housings affected the rotational efficiency of the shafts. In some cases, the fit between the bushing and bearing was either too tight or too loose, which caused either excessive drag or vibration. As a solution, tighter quality control should be implemented during fabrication, especially in turning and milling processes, to ensure consistent tolerances and better alignment of rotating components.

4. Conclusion

This research successfully carried out the design, fabrication, and performance evaluation of a customized transmission system for the Garuda UNY UG-24 urban vehicle. Through the implementation of the 4D development method (Define, Design, Develop, and Disseminate), the transmission was adapted to meet the vehicle's high-torque demands. The performance test demonstrated a 75% success rate in gear shifting smoothness and overall functionality, although several technical weaknesses were identified. These findings provide valuable insights for future improvements and establish a solid foundation for further optimizing energy-efficient vehicle systems.

Conflict of interest

The authors declare no conflict of interest.

References

[1] G. P. Mustaqim and T. Wahjoedi, "Effectiveness of Student Participation in Campus Organizations," *INCOME: Innovation of Economics and Management,* vol. 3, no. 3, pp. 29-35, 2024.

[2] K. Haryana, Z. Arifin, I. N. Yoga, N. W. Purnomo, and M. Z. Naresworo, "The effect of tire pressure on car fuel consumption Garuda urban gasoline 19, in the Shell Eco-Marathon competition Asia 2019, Malaysia," 2024, vol. 3145: AIP Publishing, 1 ed., doi: https://doi.org/10.1063/5.0216922.

[3] T. Paul, "Design of chassis, impact attenuator, suspension and aerodynamic systems of a formula SAE car," 2019.

[4] D. C. Barton and J. D. Fieldhouse, *Automotive Chassis Engineering*. Springer, 2018.

[5] W. Zhang and J. Xu, "Advanced lightweight materials for Automobiles: A review," *Materials & Design,* vol. 221, p. 110994, 2022, doi: https://doi.org/10.1016/j.matdes.2022.110994.

[6] G. Lechner and H. Naunheimer, *Automotive transmissions: fundamentals, selection, design and application*. Springer Science & Business Media, 1999.

[7] M. R. Ahssan, M. Ektesabi, and S. Gorji, "Gear ratio optimization along with a novel gearshift scheduling strategy for a two-speed transmission system in electric vehicle," *Energies,* vol. 13, no. 19, p. 5073, 2020, doi: https://doi.org/10.3390/en13195073.

[8] S. Zhou, J. Liu, C. Li, and B. Wen, "Nonlinear behavior of a spur gear pair transmission system with backlash," *Journal of Vibroengineering,* vol. 16, no. 8, pp. 3850-3861, 2014.

[9] X. Li, Q. Cao, X. Zhang, and X. Gao, "Research on the influence of backlash and bearing clearance on torsional vibration of pure electric vehicle gear system," *International Journal of Vehicle Noise and Vibration,* vol. 17, no. 3-4, pp. 273-288, 2021, doi: https://doi.org/10.1504/IJVNV.2021.123435.

[10] R. B. Indaryanti, H. Harsono, S. Sutama, B. Murtiyasa, and B. Soemardjoko, "4D Research and Development Model: Trends, Challenges, and Opportunities Review," *Jurnal Kajian Ilmiah,* vol. 25, no. 1, pp. 91-98, 2025, doi: https://doi.org/10.31599/na7deq07.

[11] M. V. Zernin, A. V. Mishin, N. N. Rybkin, S. V. Shil'Ko, and T. V. Ryabchenko, "Consideration of the multizone hydrodynamic friction, the misalignment of axes, and the contact compliance of a shaft and a bush of sliding bearings," *Journal of Friction and Wear,* vol. 38, pp. 242-251, 2017, doi: https://doi.org/10.3103/S1068366617030163.

[12] J. Singh, A. Verma, R. Kunal, A. Balpande, and M. Dhane, "Shifter fork stiffness correlation to gear shift quality," *SAE International Journal of Commercial Vehicles,* vol. 6, no. 2013-01-2447, pp. 498-509, 2013, doi: https://doi.org/10.4271/2013-01-2447.

[13] W. Luo, G. Liu, and H. Wang, "Study on Anti-backlash Mechanism Used in Precise Transmission: A Review," 2021: Springer, pp. 1449-1470, doi: https://doi.org/10.1007/978-981-16-7381-8_89.

[14] W. Tang, Y. Zhou, H. Zhu, and H. Yang, "The effect of surface texturing on reducing the friction and wear of steel under lubricated sliding contact," *Applied surface science,* vol. 273, pp. 199-204, 2013, doi: https://doi.org/10.1016/j.apsusc.2013.02.013.

[15] D. T. Jelaska, *Gears and gear drives*. John Wiley & Sons, 2012.

[16] H. Du, W. Xiong, H. Wang, and Z. Wang, "A review: virtual assembly of flexible cables based on physical modeling," *Assembly Automation,* vol. 40, no. 2, pp. 293-304, 2020, doi: https://doi.org/10.1108/AA-04-2018-056.

[17] M. Blomgren, "Modeling and control of engaging gears in gearboxes without synchromesh towards specific angles between gear and coupling sleeve," ed, 2019.

[18] E. Garosi, F. Sheikh, and M. Goodarzi, "Ergonomic Interventions in Risk Reduction," 2025, doi: 10.5772/intechopen.1008463.