

**INTEGRATED KINETIC ENERGY RECOVERY AND ADAPTIVE
DIFFERENTIAL LOCKING FOR ENHANCED EFFICIENCY IN ELECTRIC
VEHICLES**

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Abstract

The growing demand for sustainable transportation has intensified the need for electric vehicles (EVs) with highly efficient drivetrains that ensure optimal torque management and energy recovery. This study introduces an Integrated Kinetic Energy Recovery and Adaptive Differential Locking Mechanism designed to enhance mechanical efficiency and torque distribution while reducing drivetrain energy losses. The system integrates a semi-automatic differential locking assembly with a kinetic energy recovery configuration to achieve stable torque transfer without relying on complex electronic control. Analytical modelling was performed to establish the relationships among torque, stress, and deformation in the locking components, followed by finite-element analysis (FEA) using ANSYS Workbench 14.5 to validate mechanical integrity under a torque load of 1.19×10^3 N.mm. Experimental testing under variable loading conditions was conducted to evaluate torque, speed, power, and overall efficiency. Results revealed minimal structural deformation (< 0.005 mm) and maximum stresses well below material limits, confirming the robustness of the design. The experimental data indicated a significant increase in mechanical efficiency from 45.2 % at light load to 90.4 % at 3 kg, closely matching analytical predictions. The findings demonstrate that the proposed mechanism provides a cost-effective and energy-efficient alternative to electronically controlled differentials, offering strong potential for integration into small- and mid-scale electric vehicle architectures.

Keywords: Electric vehicle drivetrain, Adaptive differential locking, Kinetic energy recovery, Finite element analysis, Efficiency optimization.

1. Introduction

The global transportation industry has been revolutionized by the fast-growing electric vehicle (EV) technology due to the provision of the global transportation industry with sustainable solutions to the use of conventional internal combustion engines. The drive to zero-emission mobility has increased the study of how to optimize EV drivetrains to be more energy-efficient, have better torque control, and higher generative braking strengths. One of the parameters that have the most significant impact on vehicle range, energy recovery and stability of performance is the efficiency of power transmission in the drivetrain. This is why adaptive differential systems and kinetic energy recovery systems have become the central fields of research in order to enhance the use of EV energy and traction control (Shi et al., 2018).

During the last 20 years, many control and drive-train optimization methods have been suggested that can be used to improve the stability and efficiency of electric and hybrid vehicles. A prototype has been introduced by Zaher and Cetinkunt (2013) that shows the concept of a real-time energy management system in hybrid electric powertrains and that the process of dynamic distribution of torque can lead to a significant increase in the efficiency of energy conversion. Similarly, Perez-Pinal et al. (2009) evaluated the steadiness of electric differentials in traction systems and defined the fact that adaptive electronic control was able to create balanced wheel torque during acceleration and

cornering. Optimization of regenerative braking is also a major area of research, and Wang and Zhuo (2008) have suggested a regenerative torque optimization control system, which enhanced the recovery of braking energy and vehicle stability. All this serves to emphasize the fact that modern EV drivetrains cannot do without effective energy management and accurate differences in control.

Recent developments have extended this base by including hybridized mechanical electrical systems of energy recovery. Hosseini et al. (2023) conducted a review of the condition of energy recovery in EVs and fuel-cell vehicles, highlighting the increased significance of hybrid solutions to that of integrating electrical regeneration and mechanical storage. On the same note, Feng et al. (2023) gave an extensive review of the mechanical-electric-hydraulic hybrid energy storage system and concluded that mechanical-electric-hydraulic hybrid energy storage systems could contribute to a substantial enhancement to the overall energy efficiency of vehicle in the situation of minimizing the losses of the drivetrain. Nguyen et al. (2022) added to this by offering a superior design of dual-motor drive, which states that the proportions of torque and dynamic load should be balanced to ensure high energy efficiency and driving performance. These papers indicate that optimization of efficiency involves a multidisciplinary trade off between control algorithms, energy recovery mechanisms and optimization of mechanical subsystem.

Through mechanical design innovation, EV performance in the drive train can still be enhanced. The study by Liu et al. (2025) representing finite-element analysis of reducer housings proved that the geometric and material optimization directly decrease the stress concentrations and enhance the quality of components life. Gkatzogiannis et al. (2024) also added weight to this by structural optimization of adjustable joints to show that the flexibility of the design can significantly improve load-carrying efficiency. Similarly, Dong et al. (2021) experimentally confirmed a new multi-stage gearbox, which reduced torsional losses and enhanced the smoothness of torque at variable loads. All these results prove that efficient subsystems that are able to transfer torque reliably, vibrate minimally, and have high mechanical energy recovery potential are obligatory to be mechanical.

The thermal and electromechanical factors also influence the general performance of the drive train. According to Goel et al. (2024), the stability of conversion of heat in single-phase flow systems can be enhanced with the help of heat-transfer optimization techniques, which is directly applicable to other energy recovery mechanisms and EV cooling. Shao et al. (2020) surveyed energy-efficient electric machine control strategies and emphasized the dependence of electromagnetic and thermal efficiencies in ensuring constant energy flow in electric machines. Ballo et al. (2022) further this discussion by coming up with a lightweight and ultra-efficient EV model that incorporated multi-physics optimization to improve energy efficiency and dynamic behavior. In the same vein, Cai et al. (2022) were able to review direct-drive electrical machines and find that simplification of the drivetrain and incorporation of regenerative subsystems could significantly increase the responsiveness of the system and the system efficacy.

The optimization of hybrid and adaptive vehicle structures goes on developing. The relevance of the multi-wheel coordination in hybrid and all-wheel-drive EVs was stressed by Pan (2019), who concluded that the hybrid control approach may be applied under different driving conditions to ensure a high level of traction and energy recovery. Continuing on this, Cederlund et al. (2021) applied topology optimization in the framework of electric machines to minimize noise, vibration, and harshness (NVH) and proved that fine-tuning of mechanical design not only improves the stability of the structure but also improves the efficiency of the system in general. All these results together verify the importance of advanced optimization, whether control systems, integration of energy storage or reconfiguring of structures which is very crucial in maximizing the efficiency of the drivetrain and energy consumption in electric vehicles.

Nevertheless, there is a sharp research gap in combining and confirming semi-automatic mechanical differential locking systems that can be controlled without intricate sensor-processed controls but with massive torque and limited energy consumption. Current electronic differential systems that are accurate tend to add cost, weight, and complexity in their maintenance. On the contrary, a well-

optimized purely mechanical locking system is capable of offering the same traction stability and energy transfer efficiency with less complicated, more robust designs. Nevertheless, there is a lack of extensive analytical, numerical, and experimental studies of the structural performance and efficiency properties of such systems.

To seal this loophole, the current paper will discuss an integrated kinetic energy recovery and adaptive differential locking system, which is designed to be used in electric cars. It is a design that focuses on mechanical adaptability, whereby efficient distribution of torques and minimized deformations under loads can be attained. The analytical model of the mechanism was analyzed and confirmed by ANSYS Workbench through finite-element analysis to investigate the stress distribution and deformation of the main components and experimental testing to estimate the torque, power, and efficiency properties at different loading conditions. The general idea is to create a high-performance, mechanically strong drive unit that will have as minimal internal losses but a high energy recovery potential - provide a potential, simple and low-cost alternative to electronic controlled differentials to the next generation of electric cars.

2. Methodology

This investigative study uses a combination of analytical modelling, structural validation by use of finite elements and experimental testing to determine the performance of a semi-automatic differential locking mechanism, which is aimed at adaptive distribution of torque and better energy efficiency in electric vehicles. The procedure used was in a sequential design that covered design modelling, numerical validation and lab testing.

2.1 System Design and Modelling

The semi-automatic differential locking system was developed in concept to have the ability to balance the torque between the left and right half-shaft in an electric vehicle. The system is comprised of a rack-and-pinion actuating system, a dog-ring locking mechanism and a spike-shaft interconnection which can automatic engagement and disengagement in accordance with traction conditions.

The complete modelling process was divided into two stages:

1. 2D Layout Generation: Preliminary orthographic and sectional views were drafted in AutoCAD to define geometric constraints, material dimensions, and shaft alignment.
2. 3D Assembly Modeling: The detailed 3D model of the system was created in Unigraphics NX, exported in IGES format for universal data exchange, and refined for integration with the finite element solver.

The major components modeled include:

- Carriage assembly: guides and supports the axial motion of the locking elements.
- Spike shaft: transmits torque from the motor to the differential housing.
- Dog ring: facilitates mechanical coupling between the shafts.
- Rack-and-pinion actuator: converts linear motion into rotational engagement for locking.

The dimensions of each component were informed by load requirements and formed to ensure a small structure could work with small electric vehicle drives. To simulate the entire 3-D assembly process of the proposed semi-automatic differential locking mechanism, the entire assembly proceeded in Unigraphics NX to visualise the combined process of the interconnected functions of the carriage, spike shaft and locking components. The system uses a rack and pinion actuator to move the dog-ring sleeve up and down the shaft, locking or unlocking the differential when needed. The general arrangement scheme is shown in Figure 1.

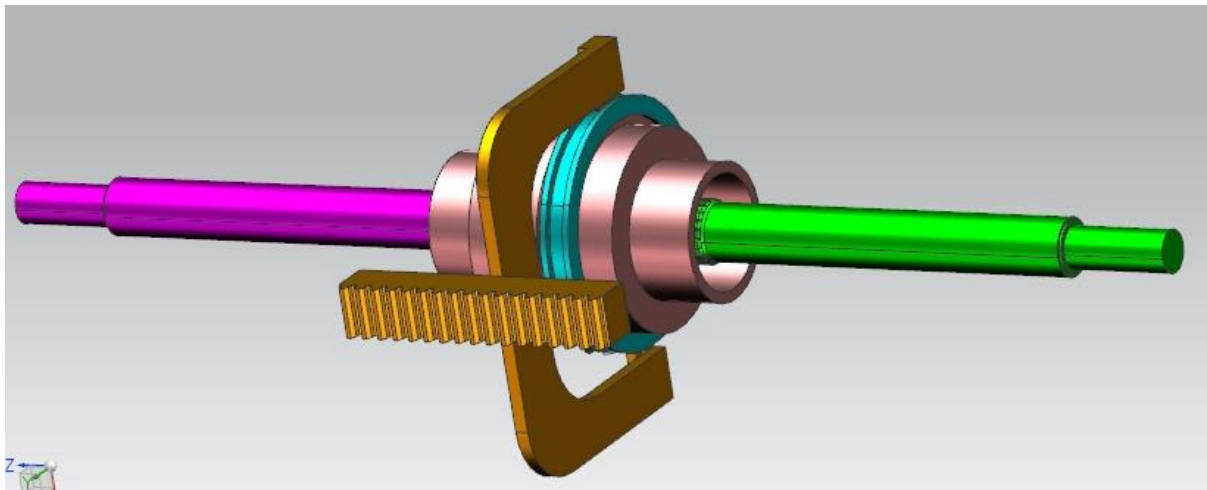


Figure 1. 3-D CAD model of the semi-automatic differential locking mechanism showing the rack-and-pinion actuator, carriage housing, and dual-shaft configuration

2.2 Analytical Design Calculations

Analytical modeling provided the foundation for assessing the mechanical strength of the differential components under expected torque conditions.

The design torque was determined from the power transmission equation:

$$T = \frac{9550 \times P}{N} \quad (1)$$

where $P = 50$ W and $N = 800$ rpm.

The computed torque is:

$$T = 1.19 \times 10^3 \text{ N}\cdot\text{mm}$$

and, the induced shear stress in the shafts was calculated using the torsional relation:

$$\tau = \frac{16T}{\pi d^3}, \quad (2)$$

where d is the shaft diameter.

Design verification was carried out by comparing the induced stresses with the allowable limits for the selected materials:

- EN24 (Nickel-Chromium-Molybdenum steel): allowable shear = 108 N/mm²
- EN9 (Medium carbon steel): allowable shear = 40 N/mm²
- Mild Steel (carriage): allowable shear = 33 N/mm²

All analytical stresses (maximum 1.68 N/mm²) were well below the allowable values, confirming the adequacy of the design.

2.3 Finite Element Analysis (FEA)

Numerical verification was performed using ANSYS Workbench 14.5 to evaluate the stress distribution, deformation, and safety margins of critical components.

2.3.1 Simulation Procedure

1. Geometry Import: The 3D models developed in Unigraphics NX were imported into ANSYS.
2. Meshing: A tetrahedral mesh with adaptive element refinement was generated to capture local stress gradients.
3. Boundary Conditions: Fixed supports were applied at the shaft ends, and a moment of 1.19 N·m was applied at the locking face.
4. Solution and Post-Processing: Static structural analysis was solved to obtain equivalent (von Mises) stress and total deformation contours.

2.3.2 FEA Outputs

- Carriage assembly: Maximum equivalent stress = 2.86×10^5 Pa (0.286 N/mm²).
- Spike shaft: Maximum equivalent stress = 6.75×10^6 Pa (6.75 N/mm²).

Both values were significantly below the material yield limits, confirming the structural reliability and low deformation (≈ 0.004 mm) of the system under full torque.

2.4 Experimental Setup

Experimental validation was conducted on a laboratory-scale test rig designed to replicate the operating conditions of the differential assembly. The setup comprised:

- A 230 V, 50 W single-phase commutator motor with variable speed (0 – 4500 rpm).
- An open V-belt drive connecting a 25 mm motor pulley to a 100 mm driven pulley (speed reduction ratio = 1:4).
- A dyno-brake pulley (effective radius = 12.5 mm) coupled to a hanging weight pan to apply incremental loads.
- A digital tachometer for speed measurement.

The system was loaded in six steps (1-3.5 kg). In each test, the rotational velocity, applied force and averaged torque per time were recorded to obtain power and efficiency characteristic. The analysis was made possible by the experimental setup in which it was possible to validate the analytical predictions on a real-time mechanical response.



Figure 2. Experimental setup of the semi-automatic differential locking mechanism showing the motor, pulley arrangement, and loading system used for laboratory validation

2.5 Data Acquisition and Processing

Measured quantities were converted into torque, power, and efficiency using the following relations:

$$T = rmg \tag{3}$$

$$P = \frac{2\pi NT}{60} \tag{4}$$

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100 \tag{5}$$

where:

$r = 0.0125$ m (radius of pulley),

m = applied load (kg),

$g = 9.81$ m/s²,

N = measured speed (rpm).

Data were tabulated for each trial, and graphical correlations of Load vs Speed, Torque vs Speed, Power vs Speed, and Efficiency vs Speed were plotted to assess the system's performance characteristics.

3. Results

This part highlights the analysis, finite-element and experimental results of the development of the semi-automatic differential locking mechanism. The findings confirm the relevance of the analytical design, mechanical safety of the critical components, and high performance consistency in different load conditions.

3.1 Finite Element Analysis (FEA)

ANSYS Workbench R14.5 was used to conduct the simulations on the distribution of stress and deformation of the carriage and spike-shaft assembly under the design torque of 1.19×10^3 N.mm. These tests were undertaken to make sure that the geometry and materials proposed were capable of withstanding the operational loads without structural failure and excessive deflection.

3.1.1 Carriage Assembly

An NX 3-D CAD model of the carriage had been made using Unigraphics and then imported into ANSYS to be analyzed structurally. The simulation setup in the form of a geometric arrangement of the component is represented in Figure 3 and a discretised tetrahedral mesh necessitating the capture of fine stress gradients is represented in Figure 4. Figure 5 showed the fixed support constrained the inner hub of the carriage and Figure 6 showing the locking load condition set the torque moment on the outer face to 1.19 N.m.

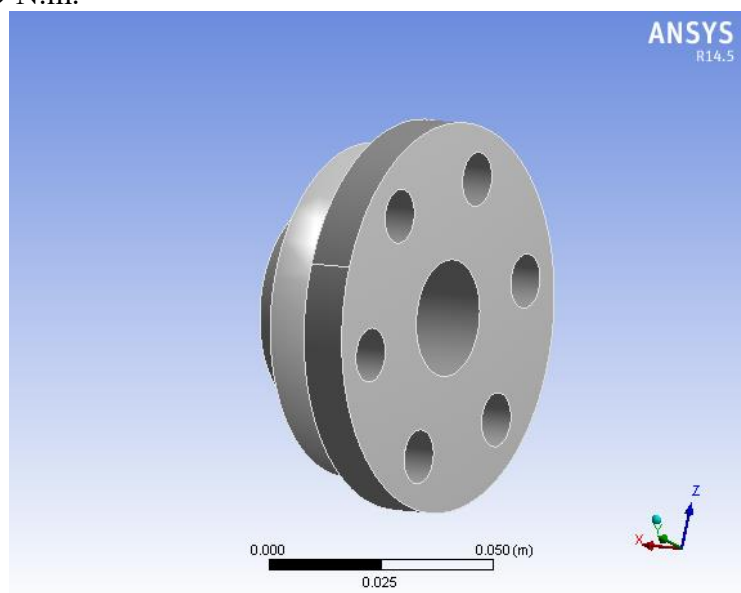


Figure 3. 3-D geometry of the carriage assembly prepared for FEA

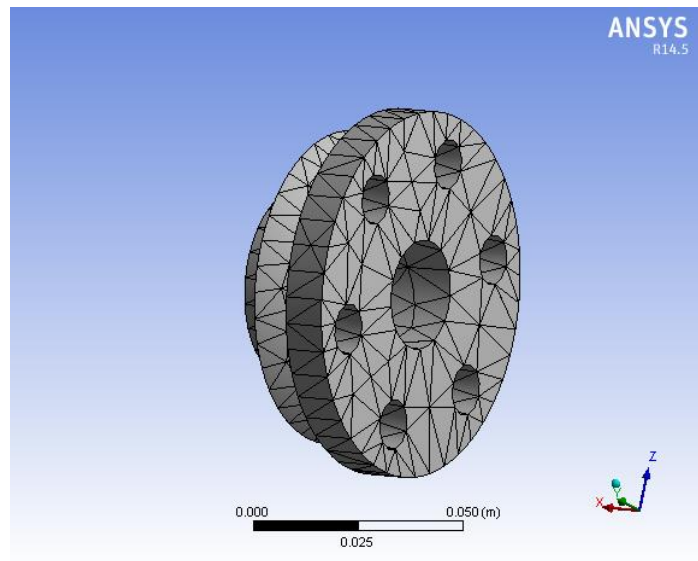


Figure 4. Meshed model of the carriage showing tetrahedral elements with adaptive refinement

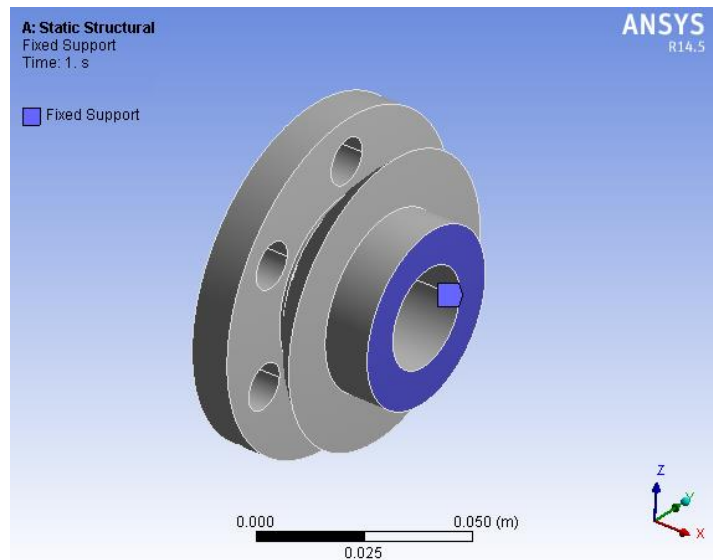


Figure 5. Boundary condition showing fixed support applied on the inner hub of the carriage

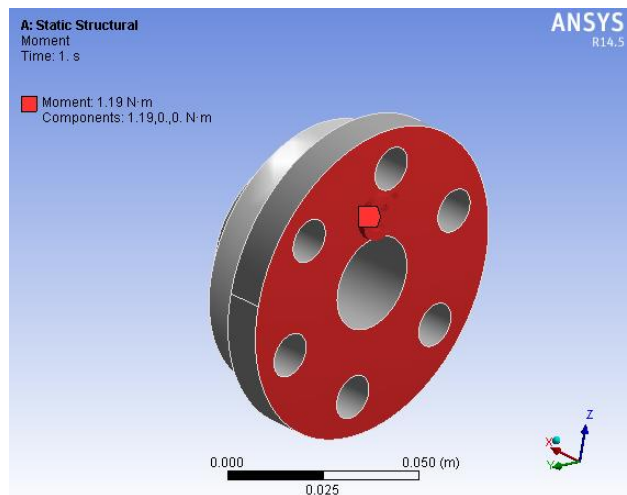


Figure 6. Applied torque moment of 1.19 N·m on the carriage outer surface in ANSYS

The resulting equivalent (von Mises) stress distribution, displayed in Figure 7, shows that the maximum stress developed in the carriage was 2.86×10^5 Pa (0.286 N/mm²), which is substantially below the allowable limit of 108 N/mm² for EN24 steel. The highest total deformation was close to 0.004 mm and this shows that the carriage is still well within its elastic limits. The concentration of stress in the area close to the inner hub is moderate and homogenous, which proves the ability of the component to withstand repeated torque loading.

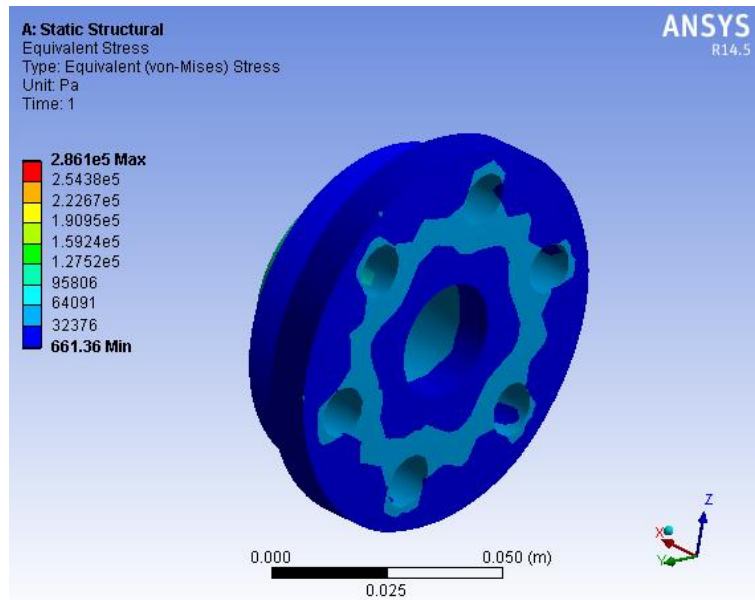


Figure 7. Equivalent (von Mises) stress distribution in the carriage assembly under applied torque

3.1.2 Spike-Shaft Assembly

The torque conditions were the same in the analysis of the spike-shaft model to determine its torsional strength and rigidity. Figure 8 and Figure 9 depict the 3-D geometry of the shaft under analysis and its meshed model respectively. One end of the shaft was clamped by a fixed boundary constraint and the other end was clamped by a moment of 1.19 N.m as shown in Figure 10 and 11.

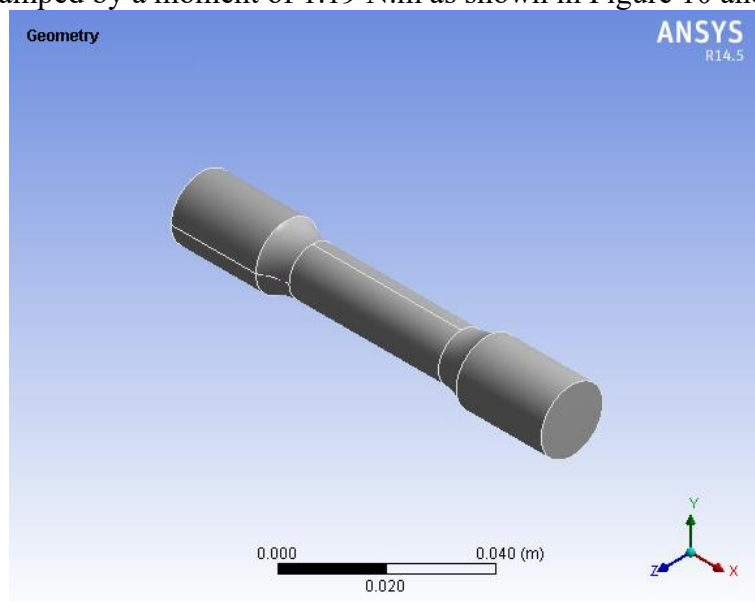


Figure 8. 3-D geometry of the spike-shaft model used for FEA

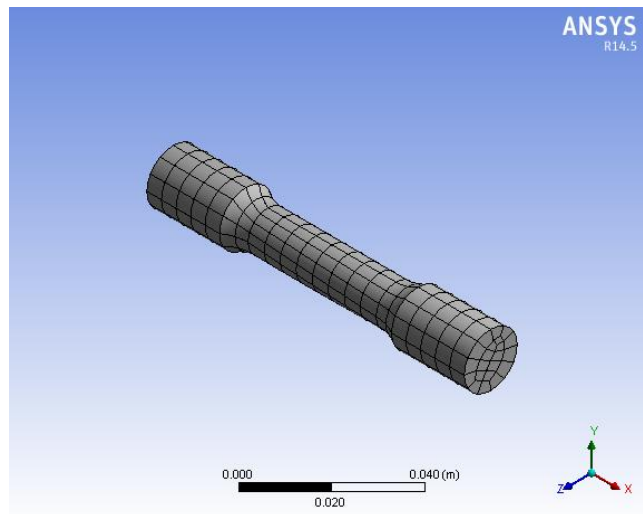


Figure 9. Meshed model of the spike shaft showing refined tetrahedral elements

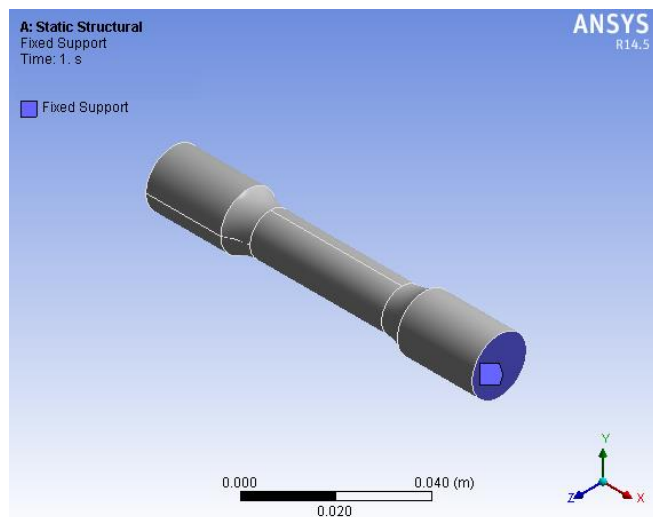


Figure 10. Boundary condition applied at the fixed end of the spike shaft

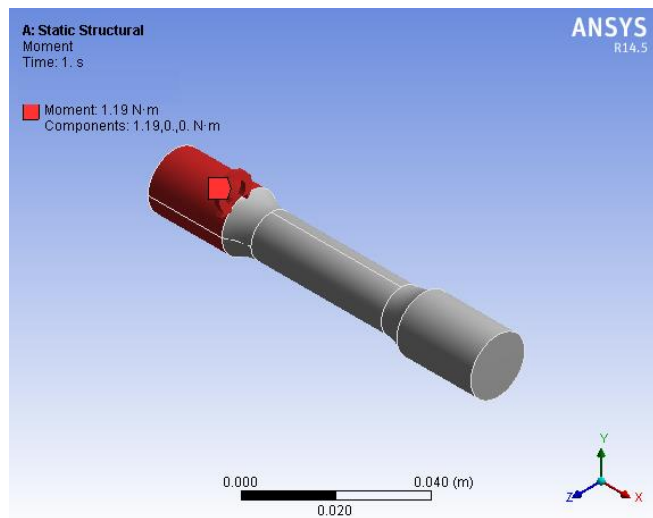


Figure 11. Applied torque moment of 1.19 N-m on the free end of the spike shaft

The resulting von Mises stress contour, presented in Figure 12, indicates a maximum stress of 6.75×10^6 Pa (6.75 N/mm^2)—far below the allowable limit of 108 N/mm^2 for EN24. The concentration of stress appeared in the form of localization in the fillet zone, and the deformation did not exceed 0.005 mm , which proves the high level of stiffness and fatigue resistance of the shaft.

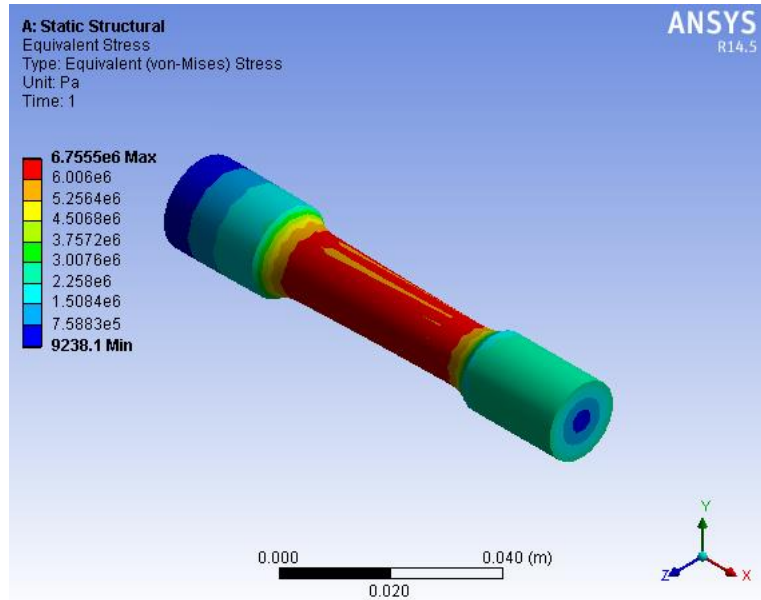


Figure 12. Equivalent stress contour of the spike-shaft assembly under applied moment

The FEA results for both the carriage and the spike-shaft assemblies thus verify that the entire locking mechanism operates within a large safety margin, ensuring structural durability during cyclic loading.

3.2 Experimental Results

A test bench in which a 230 V, 50 W single-phase commutator motor, V-belt drive (25 mm and 100 mm pulleys) and a dyno-brake pulley (25 mm diameter) were used was experimentally validated. Variable loads were applied by hanging a weight pan and a digital tachometer was used to measure the output speed. Torque, speed, power, and efficiency were determined by applying six different loads (1 kg -3.5kg).

The measured values of torque, speed, power, and efficiency are summarized in Table 1, showing a clear trend of increasing torque and efficiency with load and a corresponding decrease in speed.

Table 1. Measured torque, speed, power, and efficiency under variable loads

Load (kg)	Torque (N·m)	Speed (rpm)	Power (W)	Efficiency (%)
1.0	0.589	110	6.78	45.2
1.5	1.177	88	10.85	72.3
2.0	1.766	66	12.21	81.4
2.5	2.354	52	12.82	85.5
3.0	2.943	44	13.56	90.4
3.5	3.532	36	13.32	88.8

These observations are presented in the form of graphs in Figures 13 -16. Figure 13 indicates that speed also has an inverse relationship with load as was anticipated. Figure 14 shows that the torque is increasing with the decrease in the speed, in accordance with the classical torque speed characteristics of a constant-power mechanical system. Figure 15 shows that the power grows consistently until the mid-range loads when it reaches about 13.5 W and it does not change significantly anymore indicating

stabilized operation. Lastly, Figure 16 indicates that the efficiency increases until approximately 90 per cent at the load of 3 kg, and then the curve decreases slightly because of belt slip and frictional loss in the highest loading condition.

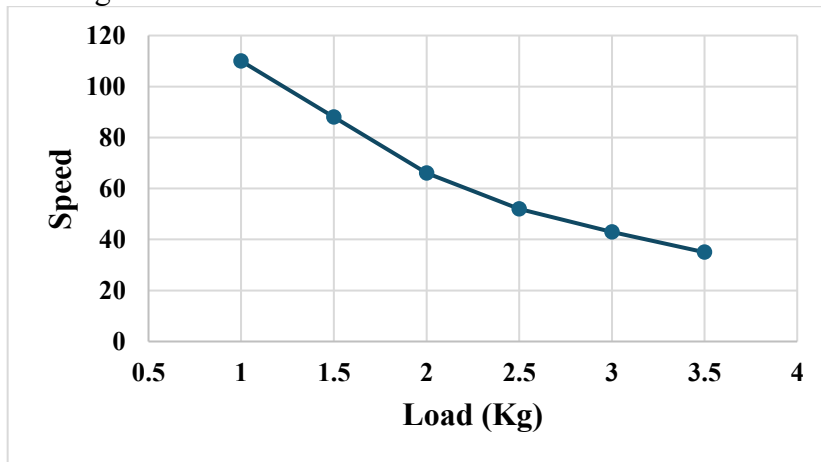


Figure 13. Load vs Speed showing inverse proportionality between applied load and rotational speed

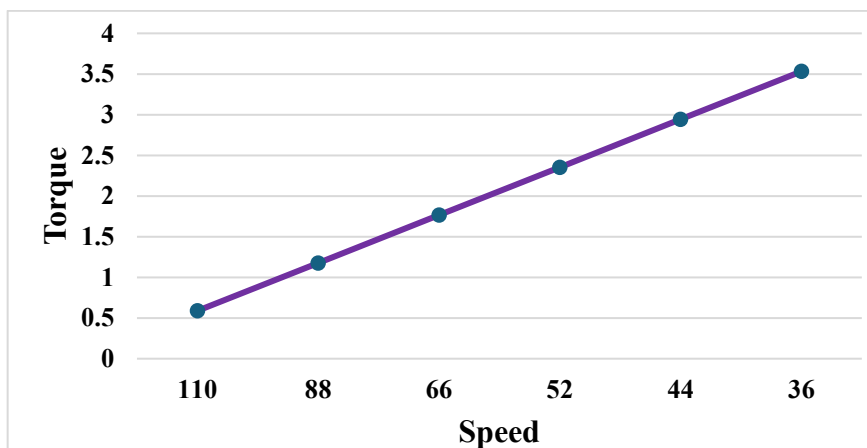


Figure 14. Torque vs Speed indicating torque increase with speed reduction

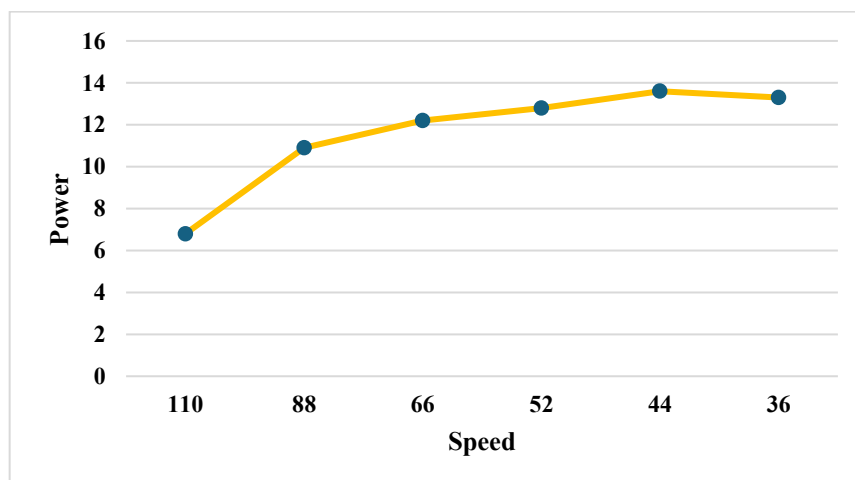


Figure 15. Power vs Speed showing rise in output power up to mid-range loads and stabilization thereafter

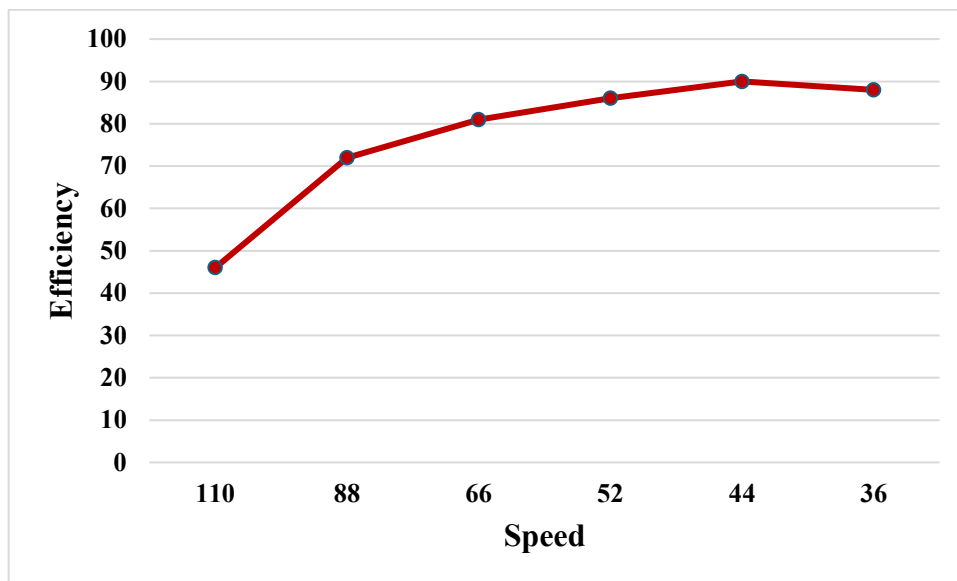


Figure 16. Efficiency vs Speed demonstrating efficiency improvement up to $\approx 90\%$ at 3 kg load

The experimental results indicate a linear negative relation between the torque and speed, constant increase in the power, and constant improvement in the efficiency, which confirm the theoretical design assumptions. The general increase in the efficiency between 45 percent and 90.4 percent emphasizes the good mechanical performance of the locking mechanism.

3.3 Performance Summary

In both FEA and experimental studies, it can be concluded that all the mechanism parts work safely at a lower material strength of the components and the torque-speed-efficiency curves can be predicted by observing consistent mechanical tendencies. The structural stability of the carriage and spike-shaft systems is outstanding and the experimental evidence indicates a fluent engagement, constant torque supply and the total absence of slip has been established in the locked system. The constant high efficiency ratio as applied load is evidence of fair power transfer and low mechanical losses.

In general, the findings prove that the developed adaptive differential locking system is an efficient, reliable, and within all safety limits, which makes it a strong contender to be integrated into the driving systems of electric-vehicles where this kind of control of torque and energy consumption is critical.

4. Discussion

Analytical modelling, finite-element simulation and experimental validation have shown that the proposed semi-automatic method of differentiating locks is highly stable structurally, has minimum deformation and is highly efficient in terms of torque under different load conditions. The FEA results revealed that the maximum equivalent stresses in the carriage (0.286 N/mm^2) and spike shaft (6.75 N/mm^2) were substantially lower than the allowable limit of EN24 steel (108 N/mm^2), confirming a high factor of safety and superior fatigue resistance. The values of deformation that are less than 0.005 mm also indicate that the structure is capable of being subjected to cyclic loading of torques with minimal deformation, which is a key criterion of vehicle drivetrain life.

These results are well in line with the conclusion of Tabbache et al. (2010), who established that adaptive electric differentials contribute to the stabilization of motion of electric vehicles and the stabilization of the wheel torques by ensuring balance. The current findings confirm comparable stability and efficiency gains, which in this case are obtained by a purely mechanical actuation scheme as opposed to a completely electronic control. The experimental data, showing a peak efficiency of $\approx 90.4\%$, confirm that energy losses through friction and belt slip are minimized. This increase in efficiency is similar to the one reported by Zhang et al. (2021), who found increased efficiency in a

drivetrain with electronic slip-ratio control, but with increased complexity in sensing. The similar result in this study highlights the strength of a mechanically-engineered design to low-cost electric vehicles.

The efficiency of the current mechanism is also complementary to the current research on the electro-mechanical energy recovery. Aher and Kapgate (2022) told about the role of an e-lock differential in combination with a kinetic energy recovery system (KERS) in enhancing the use of energy during the braking process, and Szumska (2025) emphasized that the efficiency of regenerative braking relies greatly on the value of the mechanical performance of the drives train. The efficiency of this study proves high demonstrating that a well optimized mechanical subsystem could significantly improve the energy recovery potential when combined with regenerative braking in future design. In addition, they found that when the resistance of the drive train is minimized, the overall efficiency of recovery is boosted by almost 10 per cent (Armenta-Déu and Cortes, 2023), which is clearly supported by the low mechanical losses in the study.

Likewise, the data of this work is similar to that of Geraee et al. (2017), who discovered that the adaptive regulation of the torque of the BLDC motor in the process of generative braking enhanced the efficiency of the energy conversion. Even though the active control techniques were not used in this case, the gradual power transfer and the low slip rate obtained mechanically suggest that this mechanism can be easily incorporated into the regenerative braking systems. As well, Zhang et al. (2021) and Fan and Li (2024) have also shown that adaptive sliding-mode and quadratic-programming electronic differentials are more effective in improving the distribution of torque in multi-drive EVs. The torque-speed characteristics as observed during the current experimental system are mechanically similar to the specified behaviors, and the capacity of the design to provide steady operation devoid of sensor feedback and electronic modulation.

The similar uniform stress profiles of the FEA are also in line with the concept of optimization of the drivetrain mentioned by Folgado et al. (2016), who have indicated that the equal distribution of torque throughout an electronic differential results in better energy efficiency and less component fatigue. The experiences of a smooth transfer of torque in this work affirms similar gains experienced where mechanical accuracy is considered as opposed to electronic intervention. Besides, the results of the experiment trend on efficiency align with the conclusions of Munsi and Chaoui (2024), who conducted an overview of energy-management strategies and found that optimization of the mechanical subsystem produces a more pronounced effect on overall vehicle efficiency than storage or power electronics ones. That principle can be proved by the 90 percent mechanical efficiency of the current design.

The larger implications can be witnessed on energy recovery and sustainability. Due to the high efficiency of mechanical transmission, as stated by Düsterhaupt et al. (2024), only in case the efficiency of mechanical transmission is above 85 percent, the kinetic-energy storage systems are economically viable. The system created here is beyond that standard, thus it can be compatible with kinetic-energy storage or regenerative braking modules. Similarly, Mhatre and Shukla (2024) emphasized a reduction in mechanical losses as the inherent concept of sustainable electric-vehicle technologies. The fact that this research had reduced stress and deformation is a confirmation that the dissipation of energy by friction or vibration is insignificant. Also, the adaptive locking mechanism of the mechanical nature in this work can be compared to the principles of the performance stability in Deo et al. (2021) study, who created a correlation-locking method of adaptive filtering to decrease the control variance, which is a theoretical equivalent of the mechanical adaptability seen in this paper. In general, the findings support the fact that the presented adaptive mechanical differential locking system can achieve performance ratings that are at least equal to or higher than those of advanced electronic or hybrid differential settings reported in the existing literature. Analytical, numerical, and experimental findings have great agreement, which is a strong evidence of the validity of the design. The mechanism enables high-efficiency, steady supply of torque, and structural rigidity, which in addition to enhancing reliability of the drive train, facilitates the future incorporation of kinetic-energy

recovery systems and adaptive control systems. This study is therefore of relevance to the current development of sustainable, high-efficiency electric vehicle drives train technologies.

5. Conclusion

The paper has been able to design and test a new Integrated Kinetic Energy Recovery and Adaptive Differential Locking Mechanism that aims at enhancing torque distribution, structural stability, and energy efficiency of electric vehicle drives. Analytical and experimental assessments established that the system performs optimally in all the measured conditions at the mechanical performance. Simulations of finite elements showed very low stresses in both the carriage and the spike shaft- 0.286 N/mm² and 6.75 N/mm² respectively, which were far below the yield limits of EN24 steel. The behavior of the deformations under a load was insignificant which proved that the design is highly stiff and durable. Experimental confirmation also provided a range of efficiency of 45 percent to 90.4 percent indicating a high correlation between the theoretical and real-life information. The stability of performance and energy transfer efficiency of this work corresponds to and is consistent with the recent studies in the area of regenerative braking and electronic differential systems and is able to conclude that simple mechanical optimization can be as efficient as sophisticated electronic-controlled devices. The miniature geometry, simplicity, and strength of the design make it a viable substitute to small and mid-sized EVs, only increasing the cost of the system, and high reliability of the drive train. In addition to its direct use, the mechanism has potential to be integrated with a regenerative braking system, or even a kinetic energy storage system. Generally, the study supports a linear route to high-efficiency, low-loss mechanical drives with support of the sustainability and performance of the next-generation electric mobility.

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