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Research Article

Experimental Study of Kinetic Energy Recovery Systems for Electric Vehicle

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ABSTRACT

Kinetic Energy Regenerative System (KERS) for electric vehicles is introduced, along with foundational information regarding its design and application. The objectives and methodology of the proposed work are delineated. The essential components for the KERS have been designed based on precise calculations, ensuring optimal system performance. The design and analysis of these components were executed using CAD modeling and ANSYS software to validate their structural integrity and functional feasibility. Following the computational analysis, a physical prototype of the KERS was developed and manufactured for experimental testing. Experimental investigations were conducted on the developed model to evaluate parameters such as theoretical wheel speed, theoretical distance traveled, actual wheel speed, and actual distance traveled for varying input wheel speeds. The results revealed that the actual wheel speed and distance traveled consistently exceeded the theoretical values for the same input conditions. These findings underscore the efficiency and effectiveness of the developed KERS model in energy recovery and performance enhancement.

Keywords: Kinetic Energy Recovery Systems (KERS); Electric Vehicles (EVs)

1. Introduction

Kinetic Energy Recovery Systems (KERS) are technologies designed to capture and store the kinetic energy that is typically lost during braking or deceleration, and later reuse it to improve vehicle efficiency. While KERS originated in motorsport, particularly in Formula 1, its principles have been adapted and are increasingly relevant for electric vehicles (EVs) to optimize energy consumption and enhance range. KERS work on the basis of Energy Capture, Energy Storage and Energy Reuse. Electric vehicles (EVs) already benefit from a form of regenerative braking as a standard feature [1-3]. However, advanced KERS can enhance the regeneration process and be more finely tuned to optimize energy recovery and energy usage. There are several ways KERS might be integrated into EVs: Regenerative Braking Systems, Dual-Mode Electric Motors and Super-Capacitor-Assisted Systems. Benefits of KERS for EVs are Improved Range, Enhanced Efficiency, Reduced Wear on Brakes, Better Power Distribution and Environmental Impact. Also some Challenges and Considerations for KERS integrated into EVs Complexity and Cost, Battery Management, Energy Storage Limitations, Trade-off with Performance. In a typical KERS system, when the vehicle decelerates or brakes, the vehicle's kinetic energy (which would otherwise be lost as heat in traditional braking systems) is captured and converted into electrical energy [4-5]. This process is done using an electric motor that operates in reverse as a generator. In EVs the captured energy is then stored in a battery or a super-capacitor, depending on the system design. EVs predominantly use batteries, but some may use super-capacitors to provide faster charge/discharge cycles. When the vehicle accelerates, the stored energy is sent back to the electric motor, assisting in propulsion. This reduces the demand on the main battery and improves overall energy efficiency. Carlos Armenta-Deu et al. (2023) analyzed the recovery of kinetic energy (KER) in electric vehicles (EVs), focusing on potential energy conversion and regenerative braking systems. They found that the maximum efficiency achieved by the regenerative braking system was 60.1%, while the potential energy conversion recovered up to 88.2% [6].

Julian David et al. (2024) explored the broader concept of energy regeneration in EVs, emphasizing the recovery and storage of mechanical energy during braking or descent. Their study demonstrated that energy recovery extends beyond braking to include inertia-based energy capture, effectively reducing heat and friction losses. This approach increased system efficiency and contributed to environmental sustainability [7]. S. Mandal et al. (2017) developed a prototype to regenerate energy from vehicle braking loads. Their electric regenerative system, tested under varying loads, showed that battery recharge rates increased with braking load: 0.80C for a maximum load of 648g over 8 seconds and 0.15C for a minimum load of 72g over 1.5 seconds. The recovered energy could power auxiliary components or supplement the main power source [8]. Mayuresh Thombre et al. (2014) introduced a Kinetic Energy Recovery System (KERS) using a flat spiral spring to store energy through compression and torsion. The system improved fuel efficiency by assisting with inertia recovery after braking and enabling instant acceleration when needed [9]. Nishad Kumbhojkar et al. (2015) applied KERS technology, typically used in Formula 1 cars, to bicycles. A flywheel stored energy during braking and reused it to reduce pedaling effort, particularly useful in frequent speed changes. They identified an optimal flywheel weight range (5–8 kg) to balance energy storage and usability [10]. P. Suresh Kumar et al. (2019) enhanced traditional regenerative braking systems in EVs with KERS, improving efficiency from 4.95% to 11.94%. This optimization extended battery life and increased energy savings, enhancing the range of EVs [11]. Sameer G. Patil et al. (2015) explored flywheel-based regenerative braking systems for bicycles [12]. These systems captured energy during deceleration and braking for reuse, improving energy efficiency and generating electricity for applications like charging devices. Their findings underscored the system's practical and environmental benefits.

A comprehensive review of the published literature has identified several critical areas requiring attention for the advancement and optimization of Kinetic Energy Recovery Systems (KERS) in electric vehicles (EVs). While traditional regenerative braking systems and KERS have been investigated as independent technologies, limited studies address their seamless integration to enhance energy recovery and overall efficiency. A detailed exploration is required to understand how KERS can synergistically interact with regenerative braking systems under varying operational conditions. Research by S. Mandal et al. (2017) and Nishad Kumbhojkar et al. (2015) has demonstrated the utility of energy storage mechanisms such as flywheels and batteries. However, the optimization of these energy storage solutions for diverse EV configurations—including passenger cars, buses, and heavy-duty vehicles—remains insufficiently explored. Future studies must focus on identifying the most effective energy storage mediums and retrieval methodologies tailored to the specific demands of different driving cycles [8,10]. Julian David et al. (2024) emphasized that energy recovery in EVs extends beyond braking events to include inertia-driven scenarios. However, further research is imperative to quantify and maximize energy recovery during coasting, cornering, and downhill descent [7].

Expanding the scope to incorporate these scenarios could enable the development of advanced systems capable of optimizing energy recovery across all driving modes. Existing research predominantly focuses on the functional performance of KERS but provides limited insight into the application of advanced materials and innovative designs aimed at reducing system weight and improving efficiency. Investigations into lightweight, high-strength, and cost-effective materials for critical components such as flywheels, torsional springs, and energy storage devices are essential for advancing the technology. Moreover, one of the most critical considerations for EV applications is the impact of KERS on battery performance and longevity. While P. Suresh Kumar et al. (2019) highlighted improvements in battery lifespan facilitated by KERS, there is a paucity of long-term studies evaluating the effects of frequent energy cycling on battery degradation and operational reliability [11]. This study represents a significant effort to address these research gaps through the development and experimental evaluation of a KERS for EVs. It aims to elucidate the influence of key design and operational parameters on system efficiency, thereby contributing to the refinement of KERS technology for enhanced performance and sustainability.

2. Kinematic Energy Recovery System Experimental setup and working

Fig. 1. Experimental setup of the Kinetic Energy Recovery Systems (KERS)

The image above shows the test rig set up of quarter car model of mechanical kinetic energy recovery system. The prime mover used is a single phase ac motor that drives the wheel shaft using an open belt drive comprising of the motor pulley, belt and reduction pulley. The wheel shaft holds the disc brake and the planetary gear hub. The pinion of the planetary gear train is fixed on to the wheel shaft. The internal gear is mounted in the internal gear ring holder which is mounted in ball bearing held on to the wheel shaft. The internal ring gear holder holds the spiral spring at the other end where in outer end of spring is fixed with the ring holder whereas the inner end is held in the lock shaft. The lock shaft Is housed in the unidirectional clutch. The brake calliper is fixed to the frame.

When the motor is started the planetary revolves around the sun pinion, but when the brake is applied and the lock shaft is held the planetary gear is locked which makes the ring gear to rotate in opposite direction and thereby the kinetic energy of the vehicle is stored in the spring. When the lock shaft is released the spring unwinds to delivers the motion to the wheel shaft thereby using the released kinetic energy to move the vehicle forward.

3. Result and discussion

Table 2. Observation table

heel speed difference	Theoretical Speed (rpm)	Theoretical distance(m)	Actual Speed (rpm)	Actual distance(m)	Effectiveness of KERS
10	27.5	18.15	31	20.46	1.127273
15	41.25	27.225	54	35.64	1.309091
20	55	36.3	76	50.16	1.381818
25	68.75	45.375	102	67.32	1.483636
30	82.5	54.45	128	84.48	1.551515
35	96.25	63.525	156	102.96	1.620779
40	110	72.6	188	124.08	1.709091

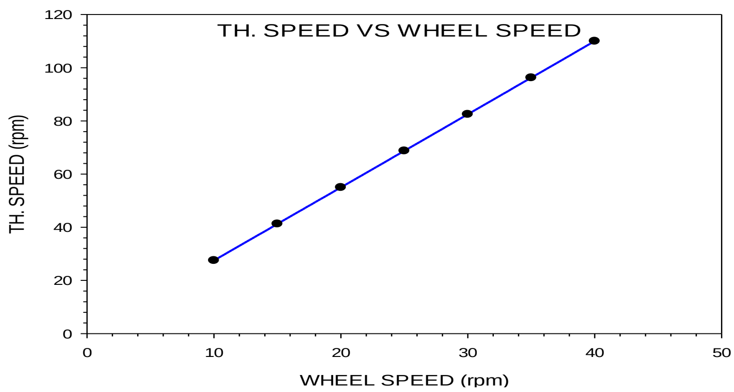

Fig. 2 Graph of Theoretical Speed Vs Wheel Speed

The fig 2 graph titled theoretical speed vs. wheel speed shows the relationship between wheel speed (measured in rpm) on the x-axis and theoretical speed (measured in rpm) on the y-axis. It observers the linear trend. The graph indicates a direct linear relationship between the two variables. As the wheel speed increases, theoretical speed also increases proportionally. This relationship suggests a consistent and proportional dependency between theoretical speed and wheel speed, possibly implying mechanical or operational synchronization, such as in systems involving gear ratios or coupled motion components.

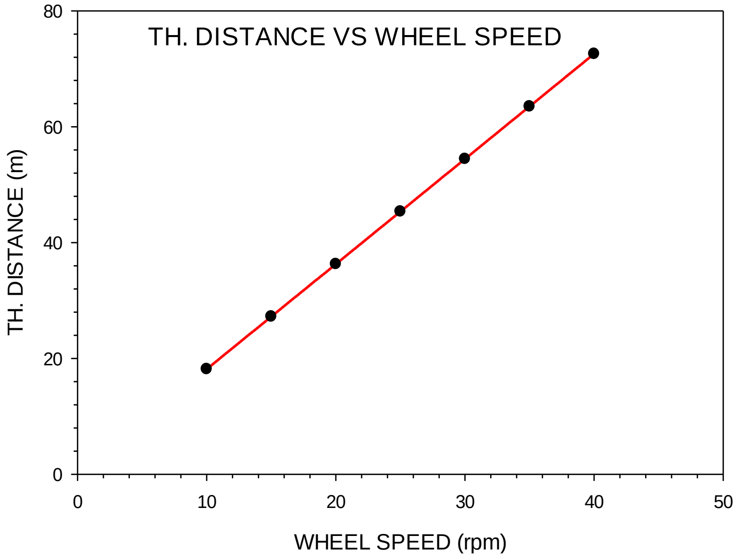

Fig. 3 Graph of Theoretical Distance VS Wheel Speed

Fig. 3. graph for theoretical distance Vs wheel speed illustrates the relationship between "Wheel Speed" (rpm) on the x-axis and "Theoretical Distance" (m) on the y-axis. The graph shows a straight line, indicating a directly proportional relationship between wheel speed and theoretical distance. As the wheel speed increases, the theoretical distance increases proportionally. This graph assumes ideal conditions where factors like friction, energy losses, and mechanical inefficiencies are negligible or absent. The theoretical model predicts a consistent increase in distance as wheel speed rises, suggesting a linear scaling in performance with speed.

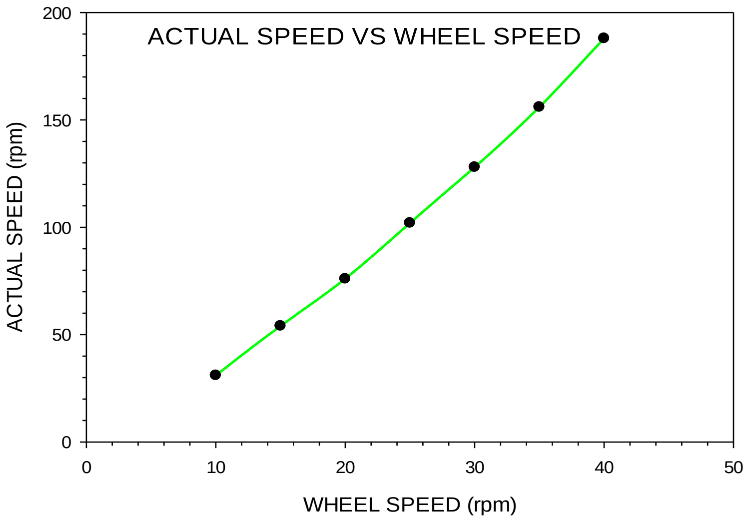

Fig. 4 Graph of Actual Speed Vs Wheel Speed

Fig. 4. graph shows actual speed Vs wheel speed depicts the relationship between "Wheel Speed" (rpm) on the x-axis and "Actual Speed" (rpm) on the y-axis. The graph shows a straight-line trend, indicating a direct proportionality between wheel speed and actual speed. As wheel speed increases, actual speed increases at a consistent rate. The slope of the actual speed vs. wheel speed graph is relatively steep, suggesting that the system converts wheel speed to

actual speed more efficiently than theoretical predictions. This could result from optimized mechanical design or enhanced energy transfer mechanisms. The actual speed's consistent increase with wheel speed indicates the absence of major operational inefficiencies or losses over the measured range. The proportionality supports a predictable system behaviour, making it suitable for applications requiring scalability with speed variations.

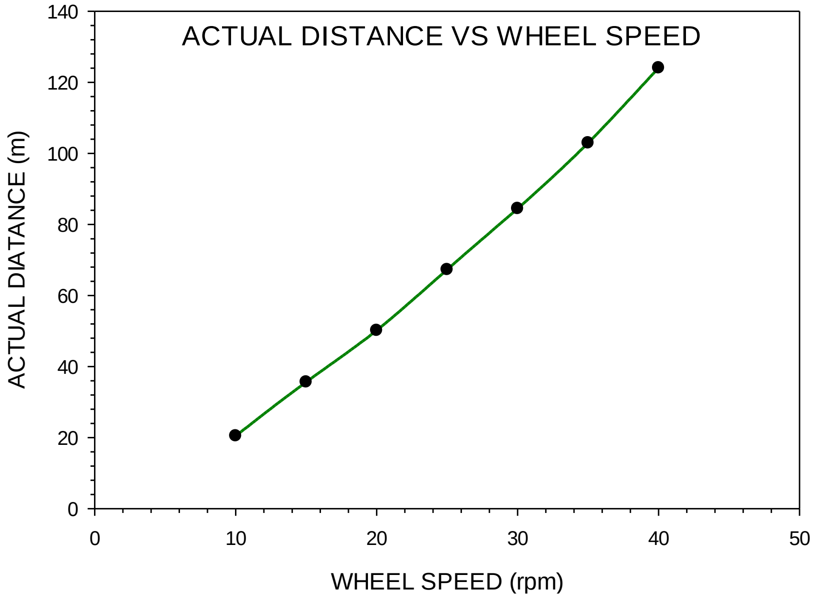

Fig. 5 Graph of Actual Distance Vs Wheel Speed

Fig. 5 shows the graph appears to show a relationship between wheel speed (rpm) and actual distance (m). The graph suggests a relationship between wheel speed and the actual distance. Generally, as the wheel speed (rpm) increases, the actual distance also increases. If the graph is linear, it indicates a direct proportionality between wheel speed and distance. For example, doubling the wheel speed could approximately double the distance traveled. As the wheel speed increases, the distance shows a clear increasing trend. There may be a point of diminishing returns or non-linear behaviour at higher speeds (this depends on whether the curve flattens towards higher rpm values). This graph could help in understanding how wheel speed contributes to movement efficiency, which might be useful in applications like robotics, vehicle dynamics, or mechanical engineering.

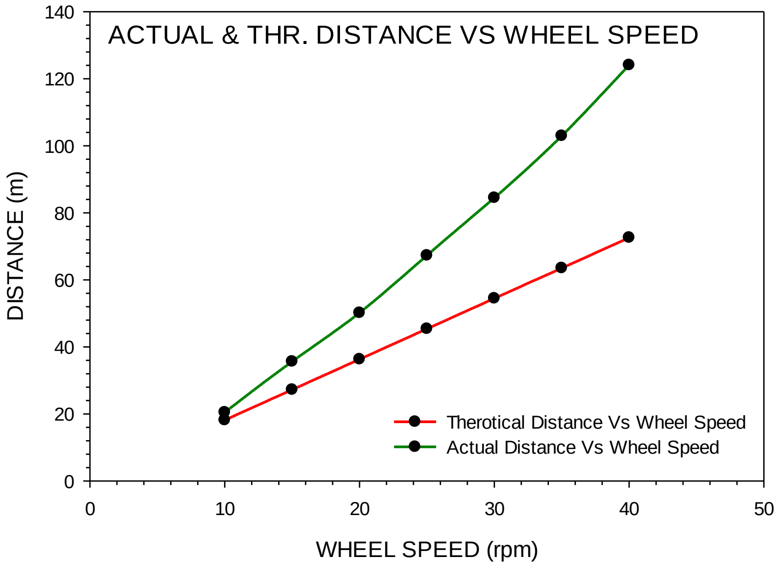

Fig. 6 Comparison Graph of Theoretical Distance & Actual Distance Vs Wheel Speed

Fig. 6 shows the graph titled "Actual & Theoretical Distance vs. Wheel Speed" provides a comparative analysis of two distance measures against wheel speed (rpm)**. At low wheel speeds**, the theoretical and actual distances may closely match, suggesting minimal discrepancies. As wheel speed increases, a gap may emerge between the two curves, indicating that the actual distance becomes less than the theoretical distance. This difference could arise due to friction, slippage, or mechanical inefficiencies that are not accounted for in theoretical calculations. Both distances show an increasing trend with wheel speed. The theoretical curve might appear more linear, while the actual curve might flatten or show deviations due to real-world factors. The discrepancy highlights the need to account for real-world losses when designing or optimizing mechanical systems. Understanding this difference can help improve system efficiency by addressing factors causing the gap.

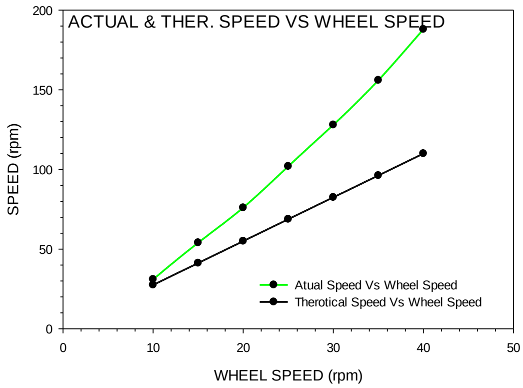

Fig. 7 Comparison Graph of Theoretical Speed & Actual Speed Vs Wheel Speed

Fig. 7 shows the graph, titled "Actual & Theoretical Speed vs. Wheel Speed", compares the actual speed and theoretical speed with respect to the wheel speed (rpm). At lower wheel speeds, the theoretical and actual speeds closely align, showing minimal deviation. As the wheel speed increases, the actual speed may lag behind the theoretical speed, creating a gap. This discrepancy likely results from real-world factors such as: Frictional losses, Slippage or mechanical inefficiencies. System lag or dynamic response limitations. The theoretical speed likely increases in a linear manner with wheel speed. The actual speed may show non-linear behaviour, especially at higher speeds, due to increasing inefficiencies. The graph underscores the importance of addressing inefficiencies in mechanical systems to bring actual performance closer to theoretical predictions. This analysis is crucial for applications where precision in speed is vital, such as robotics, automotive systems, or industrial machinery.

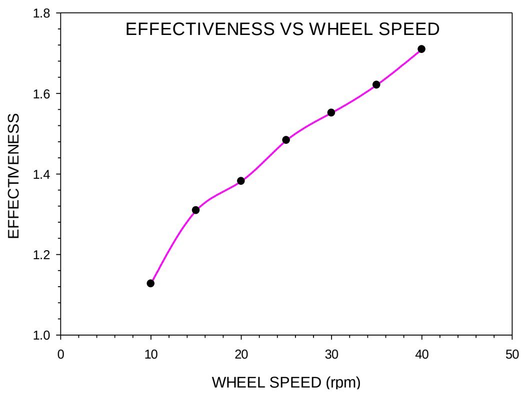

Fig. 8 Comparison Graph of Effectiveness Vs Wheel Speed

Fig. 8 show the graph titled "Effectiveness vs. Wheel Speed" appears to plot the relationship between wheel speed (in RPM) and effectiveness (no unit specified but presumably a performance metric). Higher wheel speeds are associated with increased effectiveness. The curve shows a generally upward trend. The rate of increase in effectiveness might reduce at higher wheel speeds (depending on the detailed curve shape, which isn't fully visible here).

4. CONCLUSIONS

✓ The experimental results demonstrate that the actual wheel speed and actual distance traveled consistently exceed theoretical values, indicating efficient energy recovery and enhanced performance of the KERS prototype.
✓ A positive correlation was observed between wheel speed and effectiveness, with effectiveness improving as wheel speed increased.
✓ The study successfully designed and validated the components of the KERS system using CAD modeling and ANSYS analysis, ensuring their structural integrity and functional feasibility.
✓ A physical prototype was developed and tested under varying conditions.
✓ The KERS model demonstrated effective energy recovery during braking and deceleration, enhancing vehicle range and reducing energy losses.
✓ The system outperformed theoretical predictions due to optimized mechanical design and energy transfer mechanisms.
✓ Comparisons between theoretical and actual results (speed and distance) revealed gaps at higher wheel speeds, likely caused by frictional losses and mechanical inefficiencies.
✓ The linear relationship between wheel speed and theoretical metrics suggests predictable scaling in ideal conditions, while deviations in actual results highlight real-world operational challenges.
✓ The KERS technology is scalable for various applications, including electric vehicles, robotics, and industrial machinery, offering improved energy efficiency and environmental sustainability.

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