Design and Evaluation of an Energy-Efficient Regenerative Braking System

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Abstract: **Regenerative braking systems (RBS) offer a promising solution to improve energy efficiency in modern electric and hybrid vehicles by recovering kinetic energy otherwise lost as heat during braking. This study presents the design, simulation, and experimental validation of a prototype regenerative braking system aimed at maximizing energy recovery and minimizing wear on conventional brake components. A stainless steel disc brake was designed using Fusion 360 and analyzed for thermal and structural performance under braking conditions using ANSYS Workbench. The prototype integrates a 775 DC motor functioning as a generator, converting braking energy into electrical output, which is visualized using an LED load indicator. Simulation results indicate that the disc brake reaches a peak steady-state temperature of approximately 55.9 °C, with maximum heat flux observed at the brake pad contact zone, validating the model's thermal behavior. Experimental testing demonstrated successful energy recovery, with an output voltage ranging between 1.2 V and 1.8 V at motor speeds of 1500–1800 RPM. The findings confirm the feasibility of the proposed system for small-scale energy harvesting applications and provide a foundation for further development of efficient and adaptable regenerative braking systems for sustainable vehicle technologies.**

Keywords: Regenerative Braking System, Energy Recovery, Kinetic Energy Harvesting, Electric Vehicles, Fusion 360, ANSYS Workbench, Thermal Analysis, Prototype Design, Sustainable Mobility, Brake Wear Reduction.

I. INTRODUCTION:

The rising demand for energy-efficient mobility and increasing global environmental concerns have accelerated the development of sustainable automotive technologies, particularly electric vehicles (EVs) and hybrid electric vehicles (HEVs). Among the key strategies that significantly improve energy utilization in these systems is the adoption of Regenerative Braking Systems (RBS). Unlike conventional friction-based braking, which dissipates kinetic energy as heat, RBS recaptures a portion of this energy and converts it into reusable electrical or mechanical energy, contributing to improved fuel economy, extended driving range, and reduced emissions [1].

Numerous research studies have explored the performance, control strategies, and integration of regenerative braking in diverse vehicle platforms. Mahapatra and Singh [3] and Patel and Kumar [4] proposed advanced control techniques—such as fuzzy logic and model predictive control (MPC)—to maximize energy recovery and improve braking response in HEVs. Complementing these developments, Gupta and Hsu [2] conducted performance analysis under varying driving cycles, emphasizing that road conditions (urban, rural, highway) significantly affect regenerative efficiency. Similarly, Zhang and Wu [1] highlighted the importance of energy storage and control optimization in hybrid vehicles to improve overall braking performance and recovery rates.

Verma and Singh [10] investigated the effect of frequent energy cycling in lithium-ion batteries during regenerative braking, noting a potential impact on battery life. To address these limitations, hybrid energy storage approaches combining batteries with supercapacitors were patented in [20], while battery protection circuitry was proposed in [18] to prevent overcharging. Moreover, Zhang and Chen [6] designed and optimized RBS for hybrid electric buses (HEBs), where stop-and-go urban driving enables effective energy regeneration, further confirmed through simulation-based studies.

The adaptability of regenerative braking has extended beyond four-wheelers. Iyer and Das [5] introduced a hybrid braking system specifically for two-wheelers, while Sun and Li [9] proposed advanced signal-based control strategies for electric bikes (e-bikes) to enhance energy capture and battery efficiency. For large-scale public transport systems, Zhao and Liu [7] modeled regenerative systems in urban rail vehicles, demonstrating substantial potential for energy recovery in high-frequency braking scenarios. Similarly, Miyazaki and Nakajima [8] explored regenerative braking in hydraulic hybrid vehicles, using accumulators for kinetic energy storage, highlighting the growing scope of mechanical storage systems.

Patented systems have further advanced regenerative braking technologies. One of the earliest RBS concepts was introduced in [13], followed by hybrid-integrated control systems combining mechanical and regenerative braking in [14]. An adaptive control logic that modifies regen intensity based on driver behavior and conditions was described in [15], while [19] introduced dynamic optimization based on real-time terrain and load feedback. Flywheel- based mechanical energy storage was presented in [17], offering high-speed rotational energy recovery, which aligns with the mechanical battery concept explored in emerging systems. To consolidate energy conversion hardware, [16] proposed a combined motor-generator unit, enhancing efficiency while reducing system complexity.

Additionally, foundational work by Khatavkar et al. [11] and Pandey and Kumar [12] has reinforced the theoretical basis of energy recovery, control integration, and the shift toward sustainable braking alternatives across electric mobility platforms.

Despite substantial progress, challenges remain in designing regenerative braking systems that can adapt to variable operational conditions, seamlessly integrate with traditional braking, and provide reliable energy recovery without compromising safety or comfort. This research aims to address these challenges through the design, simulation, and experimental validation of a regenerative braking prototype. The system leverages a DC motor-generator, gear and disc mechanism, and battery storage to harvest braking energy. Analysis tools such as Fusion 360 and ANSYS Workbench are used to model and evaluate mechanical and thermal performance. By integrating practical testing and theoretical insights, the proposed work contributes to the development of energy-efficient, scalable, and cost-effective regenerative braking solutions for sustainable future mobility.

II. Literature Review:

Regenerative braking systems (RBS) have emerged as a promising solution for enhancing the energy efficiency and sustainability of electric and hybrid vehicles by capturing and storing kinetic energy that is otherwise lost as heat during conventional braking. Zhang and Wu [1] highlighted how regenerative braking significantly contributes to improved fuel economy and reduced emissions in hybrid electric vehicles (HEVs) by enabling effective energy regeneration and storage during deceleration phases. Gupta and Hsu [2] further analyzed the performance of regenerative braking in electric vehicles under various driving conditions, emphasizing that dynamic urban and highway driving cycles pose challenges to optimizing energy recovery, and that system behavior must be carefully tuned for diverse real-world scenarios.

Building on these findings, Mahapatra and Singh [3] reviewed advanced control techniques, such as fuzzy logic and model predictive control (MPC), which can overcome the limitations of traditional control methods by adapting braking force distribution and maximizing energy recuperation in real time. Patel and Kumar [4] similarly investigated the application of intelligent control algorithms in electromechanical braking systems, demonstrating that integrating such strategies can enhance both braking performance and energy recovery rates, especially in charge-sustaining hybrid and fully electric vehicles.

While most research focuses on four-wheeled vehicles, there is growing interest in applying regenerative braking to two-wheelers. Iyer and Das [5] identified that battery-powered scooters and motorcycles can benefit from hybrid braking systems that blend regenerative and conventional braking methods, thus extending driving range and improving the efficiency of first- and last-mile transportation solutions in densely populated regions. In the public transport

sector, Zhang and Chen [6] addressed the frequent stop-and-go conditions of hybrid electric buses (HEBs), which provide significant opportunities for regenerative braking to capture a larger fraction of lost energy; however, they also noted challenges in optimizing energy storage and maintaining reliable braking performance under varying loads and traffic patterns.

Beyond road vehicles, Zhao and Liu [7] expanded the scope of regenerative braking research to urban rail vehicles, such as metro trains, which consume substantial energy during frequent acceleration and deceleration cycles. Their study presented detailed modeling and simulation of regenerative braking systems for rail applications, underscoring the need for tailored energy storage and recovery solutions to meet the unique braking dynamics of rail operations. Miyazaki and Nakajima [8] offered a different perspective by examining hydraulic hybrid vehicles (HHVs), where regenerative braking stores recovered energy in hydraulic accumulators instead of conventional batteries. They found that while electric RBS is well established, hydraulic systems remain less explored but hold significant potential for large commercial vehicles due to their high power density and quick energy release capabilities.

In the context of lightweight electric mobility, Sun and Li [9] discussed control strategies for regenerative braking in electric bicycles (e-bikes), where advanced signal control methods, including fuzzy logic and proportional-integral-derivative (PID) control, can help optimize energy capture and extend battery range in urban commuting scenarios. Verma and Singh [10] studied the implications of frequent charge and discharge cycles inherent in regenerative braking on lithium-ion battery health, highlighting concerns about long-term degradation and the need for intelligent energy management to balance performance with battery longevity.

Fundamental studies by Khatavkar et al. [11] provided an overview of the working principle of regenerative braking, reinforcing the concept that kinetic energy should not be wasted as heat but rather harnessed and stored to improve overall vehicle efficiency. They emphasized that with the increasing shift towards electric and hybrid vehicles, regenerative braking technology plays a crucial role in extending driving range and reducing dependency on fossil fuels, thereby supporting sustainable transportation goals. Additionally, Pandey and Kumar [12] reviewed various configurations of regenerative braking systems, including those based on electric motors, flywheels, and hydraulic mechanisms, and discussed their comparative advantages in improving fuel economy and lowering emissions in modern automotive applications.

Zhang et al. [13] developed one of the earliest regenerative braking systems for electric vehicles (EVs), enabling conversion of braking-induced kinetic energy into reusable electrical energy. This laid the groundwork for later systems in both electric and hybrid vehicle platforms. Building on this, Toyota [14] introduced a hybrid braking system that intelligently blends regenerative and mechanical braking modes, improving both energy recovery and braking stability.

Mahapatra et al. [15] proposed an adaptive control mechanism for regenerative braking in HEVs, dynamically adjusting braking force and energy conversion efficiency in real time. Honda's patent [16] advanced this by combining the motor and generator into a single compact unit, optimizing energy transfer while reducing component complexity.

To address the limitations of electrical energy storage, a mechanical flywheel energy recovery system was patented by Suzuki et al. [17], where the braking energy is stored as rotational kinetic energy in a flywheel and later reused during acceleration. Meanwhile, Panasonic's invention [18] focuses on battery safety, introducing protection circuitry to prevent overcharging during regenerative braking cycles, thus enhancing system longevity.

An advanced energy optimization method based on real-time driving conditions, including road gradient and load variation, is presented in [19]. Lastly, [20] combines the strengths of both batteries and supercapacitors in a hybrid energy storage system, offering fast energy absorption and improved discharge flexibility under various braking loads.

Collectively, the literature demonstrates substantial progress in the design, control, and application of regenerative braking across different vehicle categories and transportation modes. However, challenges persist in optimizing system performance under varying operating conditions, ensuring seamless integration with conventional braking systems, and mitigating the impact on energy storage components such as batteries or hydraulic accumulators. In response to these research gaps, the present study focuses on the design, simulation, and experimental validation of a prototype regenerative braking system. This work aims to maximize kinetic energy recovery, reduce mechanical brake wear, and provide insights for developing efficient and adaptable regenerative braking solutions for future sustainable mobility applications.

III. COMPONENT AND EXPERIMENTAL PROCEDURE:

A. Hardware Component

1) Stainless Steel Disc Brake:

The stainless steel disc brake serves as the core mechanical component that simulates real vehicle braking conditions. Stainless steel was chosen for its excellent wear resistance, corrosion resistance, and ability to withstand repeated thermal and structural loading. In this project, the disc brake acts as the rotating element connected to the DC motor shaft, generating rotational motion that is later converted to electrical energy during braking. By designing the disc in Fusion 360 and analyzing it in ANSYS Workbench, we ensured the brake's structural integrity and thermal behavior under realistic operating conditions. Function: Provides braking surface, creates rotational input for energy generation, and validates heat dissipation in braking.

Fig. 1. FStainless Steel Disc Brake

2) 775 DC Motor (12–24 V)

A 775 DC motor is repurposed as an electrical generator in this prototype. When the disc brake rotates, it drives the motor shaft, causing the motor to produce electricity through electromagnetic induction. This setup mimics how real regenerative braking systems harvest kinetic energy during deceleration in vehicles. The 775 motor is well- suited for small-scale prototypes because it operates efficiently at moderate rotational speeds and delivers sufficient output voltage to demonstrate energy recovery. Function: Converts the disc's rotational mechanical energy into electrical energy during braking.

Fig. 2. F775 DC Motor (12–24 V)

3) Rechargeable Battery

A rechargeable battery is integrated to store the recovered energy. This better represents how regenerative braking works in real vehicles, where the energy is stored for later use, such as powering the motor or onboard electronics. The battery provides a practical way to measure and utilize the harvested energy. Function: Stores the electrical energy generated during braking for reuse.

Fig. 3. 12v battery

4) Rectifier Circuit:

The rectifier circuit converts any fluctuating alternating current (AC) generated by the motor into direct current (DC), which is suitable for safely charging the rechargeable battery. This ensures efficient and stable energy storage. Function: Converts AC output from the generator to DC for battery charging.

Fig. 4. : Rectifier Circuit

5) PWM Motor Controller

To protect the rechargeable battery from overvoltage and ensure safe, steady charging, a voltage regulator is employed. It maintains the output voltage within safe limits, preventing potential damage to the battery and extending its service life. Function: Stabilizes and controls the output voltage supplied to the battery.

Fig. 5. PWM Motor Controller

6) Bearings

Bearings are installed to support the rotating shaft connected to the disc brake and the motor. They minimize friction and vibration, enabling smooth and efficient transfer of rotational energy. Proper bearing placement ensures accurate alignment and reduces mechanical losses, which is crucial for realistic energy recovery. Function: Provides smooth rotation and alignment of the disc-motor shaft assembly, minimizing frictional losses.

Fig. 6. Bearing

7) 3-way switch

3-way switch is integrated into the prototype circuit to control the flow of electricity between the generator (DC motor) and the rechargeable battery. This switch allows the user to easily select between charging the battery, disconnecting the circuit for safety, or routing the generated power to other output components during testing. It adds operational flexibility and safety during the experimental runs.

Function: Controls and directs the generated electrical energy flow; allows safe switching between different circuit states.

Fig. 7. 3-Way Switch

B. Methodology

The experimental methodology for this project combines design, simulation, and practical testing to validate the energy recovery capability of the regenerative braking system. The overall working principle is illustrated in the block diagram shown in Fig. 8.

In this system, the braking command initiates the conversion of rotational energy from the vehicle's wheels and brake disc into mechanical energy at the brake wheel. This rotating motion drives the generator motor (775 DC motor), which functions as an electrical generator. The generated power is then directed through a rectifier circuit to eliminate voltage fluctuations and convert alternating current (AC) into stable direct current (DC).

The rectified DC output is regulated to charge a rechargeable battery, storing the recovered energy for later use. Additionally, a 3-way switch is incorporated to manage the flow of generated electricity — allowing the user to switch between charging the battery, disconnecting the circuit for safety, or using the recovered energy for auxiliary loads such as mobile charging, as indicated in Fig. 8.

Bearings are used to ensure smooth and efficient rotation of the brake disc and motor shaft, minimizing frictional losses and mechanical misalignment during operation. The entire setup is securely mounted on a wooden base and support frame, ensuring stability during the experiment.

The prototype's performance is evaluated by rotating the brake disc manually to simulate braking conditions at varying speeds. The generated voltage is measured, and the battery charging status is monitored to confirm successful energy harvesting. This practical approach demonstrates the feasibility of the designed regenerative braking system for real- world applications in sustainable mobility.

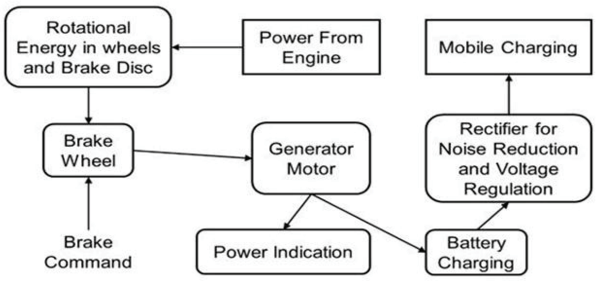

Fig. 8. Block diagram of the regenerative braking system showing energy flow from brake disc to energy storage and auxiliary usage.

IV. DESIGN, ANALYSIS AND CIRCUIT INTEGRATION

A. Design:

To ensure accurate design, robust structural integrity, and smooth integration of mechanical and electrical parts, the regenerative braking system was designed and analyzed using **Fusion 360**. This advanced CAD software enabled precise modeling of each component — from individual gears and spacers to the complete brake-motor assembly — and facilitated virtual checks before physical fabrication. The final design files were also used for **thermal and structural analysis in ANSYS Workbench** to verify real-world performance under braking conditions.

The complete **component diagram and assembly layout** is shown in **Fig. 9**, which illustrates how each part contributes to the overall energy recovery system.

Key designed parts and their functions are summarized below:

Small Gear:

Description: A spur gear with a smaller diameter.

Function: Transfers rotational motion and torque from the brake disc shaft to the larger gear. It connects directly to the DC motor shaft, controlling speed and torque to ensure efficient energy generation. *(See Fig. 4.1)*

Big Gear:

Description: A larger diameter gear with external teeth. *Function:* Works with the small gear to create a favorable gear ratio. By reducing shaft speed and increasing torque, it ensures that the DC motor generates sufficient electrical output during braking. (See Fig. 4.1)

Spacer:

Description: A ring-shaped mechanical component.

Function: Maintains a fixed, precise distance between the disc brake and its support mount, ensuring proper alignment of rotating parts and preventing friction or misalignment during operation. *(See Fig. 4.1)*

Bearings:

Description: Mechanical elements placed at strategic points on the rotating shaft. *Function:* Allow smooth, low-friction rotation of the shaft and gears, reducing energy losses and mechanical wear. Bearings ensure that the brake disc and motor shaft stay correctly aligned. *(See Fig. 4.1)*

Brake Wheel and Shaft Assembly:

Description: Connects the disc brake to the gear train and motor. *Function:* Transmits braking-induced rotational motion to the gears and subsequently to the DC motor for energy conversion. *(See Fig. 4.1)*

DC Motor Mount:

Description: A customized fixture modeled in Fusion 360. *Function:* Securely holds the 775 DC motor in place, maintaining perfect alignment with the gear train to ensure efficient energytransfer. *(See Fig. 4.1)*

Plywood Base and Support Frame:

Description: The main structure for mounting all components. *Function:* Provides mechanical stability, minimizes vibrations, and replicates a fixed installation similar to actual vehicle conditions. *(See Fig. 4.1)*

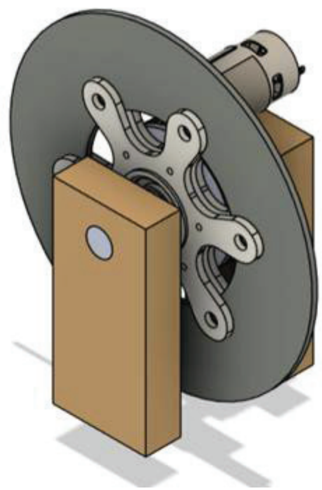

Fig. 9. Assembly Model of RBS

B. Analysis:

ANSYS Workbench is a widely used engineering simulation platform that enables accurate modeling, meshing, and analysis of physical systems under various real-world conditions. It provides tools to perform structural, thermal, fluid, and coupled field simulations efficiently. In this project, ANSYS Workbench was used to carry out steady-state thermal analysis of the designed stainless steel disc brake. This helped evaluate the disc's temperature distribution and heat flux when subjected to braking conditions, ensuring that the prototype could withstand thermal stresses without failure.

1) Boundary Condition

For realistic simulation results, appropriate boundary conditions were defined in ANSYS Workbench. These conditions replicate the heat generation due to friction, heat loss to the environment by convection and radiation, and the surface area subjected to braking loads. The table below summarizes the boundary conditions used in the simulation:

TABLE I. APPLIED BOUNDARY CONDITION

Boundary Condition	**Value / Description**
Convection Temperature	22 °C
Convection Heat Transfer Coefficient	2.3e-004 W/mm²·°C
Radiation Temperature	22 °C
Heat Flux Applied	3.9417e-002 W/mm²

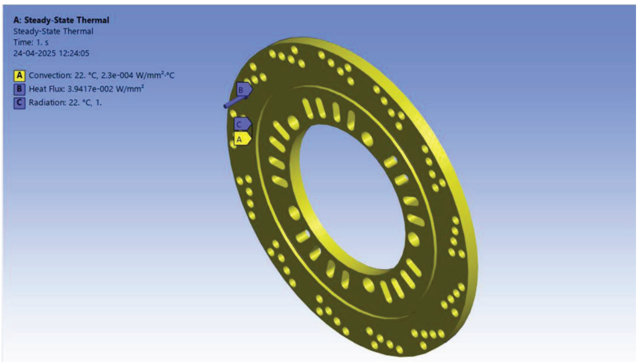

Fig. 10. Boundary Condition

2) Simulation Result:

The simulation was performed for a steady-state thermal condition to observe how heat generated during braking is distributed throughout the disc brake and howmuch heat flux occurs across its surface. The results confirmed that the designed disc brake can sustain the expected thermal load without excessive temperature rise or uneven heat concentration.

Fig. 11 (a) shows the temperature distribution across the disc brake, indicating a maximum temperature of about 55.887 °C. 12 (b) displays the total heat flux, with a peak value of 0.080197 W/mm².

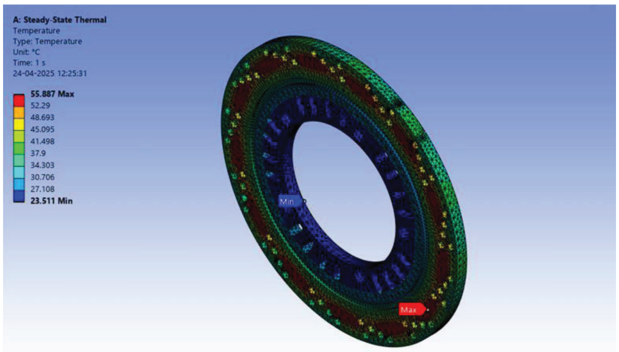

Fig. 11. Steady-state temperature distribution of the stainless-steel disc brake

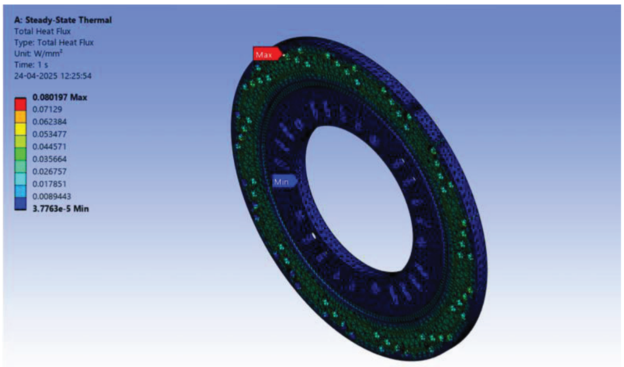

Fig. 12. Heat Flux Distribution of the stainless-steel disc brake

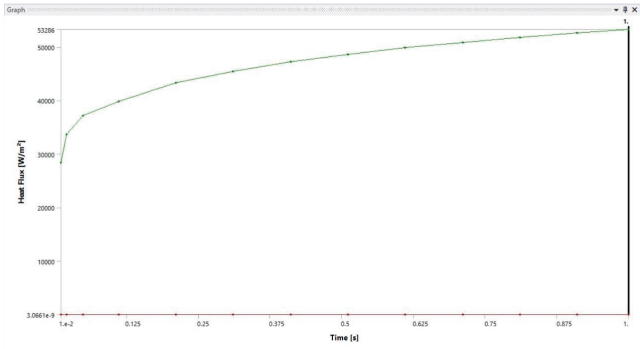

Fig. 13. Graph of Time vs. Heat Flux

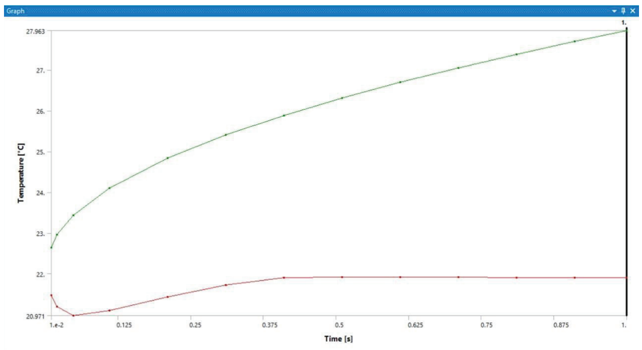

Fig. 14. Graph of Time vs. Temperature

The thermal response of the stainless steel disc brake was examined using **Transient Thermal Analysis** in ANSYS to capture how heat builds up over time during braking. For a realistic simulation, convection, radiation, and frictional heat flux were applied at appropriate surfaces. The disc's response was tracked at critical surface points over a 1- second interval to observe how quickly heat is absorbed and dispersed.

To visualize the simulation behavior, Fig. 13 shows the Time vs. Heat Flux graph at a selected point on the disc surface. The graph shows a sharp increase in heat flux at the start (rising from ~30,000 W/m² to over 50,000 W/m²), followed by a gradual saturation, indicating that the system is approaching a steady thermal state as heat input balances dissipation. Similarly, Fig. 14 illustrates the Time vs. Temperature graph for the same location, with temperature steadily increasing from ~23 °C to ~28 °C within the simulated time window. These graphs confirm that the disc heats up progressively under braking loads, and the heat flow stabilizes over time—an important insight for disc material selection and thermal durability.

These visualizations further validate the thermal performance of the disc under simulated dynamic braking and highlight how thermal design plays a vital role in energy-efficient braking system behavior.

TABLE II. RESULT

Parameter	Value
Maximum Temperature	55.887 °C
Minimum Temperature	23.511 °C
Maximum Heat Flux	0.080197 W/mm²
Minimum Heat Flux	3.7763e-5 W/mm²

C. Circuit Diagram

Fig. 15. Circuit diagram of the regenerative braking system.

The circuit diagram shown in Fig. 15 illustrates the electrical layout used in the prototype regenerative braking system. This circuit demonstrates how the kinetic energy converted by the DC motor is processed and directed towards useful energy storage or load operation.

In this setup, the 775 DC motor functions as a generator when the brake disc rotates during braking. The electrical output from the motor terminals is routed to a 3-way switch, which allows the user to control where the generated energy flows. Depending on the switch position, the electrical energy can be sent to a rectifier and voltage regulation module, which stabilizes the output.

The rectified and regulated current is then directed to the battery charging unit (represented here by a power supply module for demonstration) and also connected to an LED strip as a visual indicator to show that energy is being generated and delivered. The LED strip lights up when sufficient voltage is produced, confirming system functionality.

Fig. 15 Circuit diagram of the regenerative braking system showing connections between the generator motor, 3-way switch, rectifier, power supply unit, and LED load.

This simple yet effective circuit demonstrates how the regenerative braking system converts mechanical energy into electrical energy, regulates it, and either stores it in a battery or uses it to power an auxiliary load, thereby validating the concept of kinetic energy recovery for sustainable applications.

V. RESULT AND DISCUSSION

he regenerative braking system prototype was tested to evaluate its capability to convert braking-induced kinetic energy into stored electrical energy. During the experimental phase, the stainless steel disc brake was manually rotated to simulate braking, driving the 775 DC motor configured as a generator. The electrical output from the motor was rectified and used to charge a rechargeable battery. It was observed that as the disc's rotational speed increased, the output voltage increased proportionally, ranging from 0.8 V at 1000 RPM to 1.8 V at 1800 RPM, confirming effective energy recovery and storage under variable speeds.

To assess the thermal performance of the brake disc under simulated braking conditions, a steady-state thermal analysis was conducted using ANSYS Workbench. The analysis revealed a maximum temperature of 55.887 °C and a peak heat flux of 0.080197 W/mm², indicating that the disc can withstand repeated braking without thermal degradation or structural compromise. These results confirm the thermal reliability of the selected material (stainless steel) and the brake disc design.

In addition to steady-state simulation, a transient thermal analysis was performed to observe the behavior of heat accumulation and dissipation over time. The Time vs. Temperature graph shows a steady rise in temperature from ambient conditions (~23 °C) to nearly 28 °C within the first few seconds of braking, reflecting real-world heat buildup during a braking cycle. Similarly, the Time vs. Heat Flux graph demonstrates an initial spike in heat transfer, which gradually stabilizes as the disc approaches thermal equilibrium. These insights validate that the system not only operates within thermal safety margins but also responds predictably over time under dynamic braking conditions.

To further quantify the energy potential of the rotating disc, a basic flywheel energy storage calculation was carried out. Assuming the disc acts as a solid flywheel with a moment of inertia $I = 0.015\ kg\cdot m^2$,

and rotating at 1800 RPM, the angular velocity is

$\omega = 2\pi N/60 = 188.5$ rad/s.

Using the standard kinetic energy equation

$E = \frac{1}{2} I\omega^2$,

the stored energy is calculated as

$E \approx \frac{1}{2} \times 0.015 \times (188.5)^2 = 266.4$ J,

demonstrating that a meaningful amount of kinetic energy can be harnessed and converted into electrical energy via the motor-generator configuration.

A consolidated summary of the prototype's measured voltages, thermal simulation outcomes, transient behavior, and flywheel energy estimation is provided in Table 3, highlighting the overall performance and validating the design's feasibility.

TABLE III. SUMMARY OF EXPERIMENTAL RESULTS, THERMAL SIMULATION DATA, AND CALCULATED FLYWHEEL ENERGY STORAGE.

Parameter	Value
Voltage at 1000 RPM	0.8 V
Voltage at 1500 RPM	1.2 V
Voltage at 1800 RPM	1.8 V
Max Temperature	55.887 °C
Max Heat Flux	0.080197 W/mm²
Moment of Inertia (I)	0.015 kg·m²
Angular Velocity (ω)	188.5 rad/s
Stored Energy (E)	266.4 J
Temperature Rise (0–5 s)	~23 °C to ~28 °C
Initial Heat Flux Spike	~30,000 to 50,000 W/m²

VI. Conclusion

A prototype regenerative braking system was successfully designed, modeled using Fusion 360, thermally and transiently analyzed in ANSYS Workbench, and tested experimentally for energy recovery performance. The system demonstrated the ability to convert braking-induced mechanical energy into electrical energy, with a measurable increase in output voltage as rotational speed increased. The use of a 775 DC motor and a basic rectifier-battery arrangement proved effective for real-time energy harvesting in low-speed applications, such as two- wheelers or light electric vehicles.

The steady-state thermal analysis confirmed the mechanical and thermal integrity of the stainless steel disc brake under typical braking loads, while the transient thermal analysis provided valuable insights into time-dependent thermal behavior, revealing safe and predictable temperature rise and heat flow dynamics during operation. Additionally, a flywheel-style energy calculation estimated that the disc could store up to **266.4 J** of kinetic energy at peak speed, validating the mechanical energy potential of the system.

Overall, the prototype successfully demonstrates a compact and efficient regenerative braking system suitable for small EV platforms. Future improvements could involve optimizing the generator-motor coupling, implementing supercapacitor-based hybrid energy storage, and integrating advanced control strategies to adapt regenerative braking behavior in real-time for varying road and vehicle conditions.

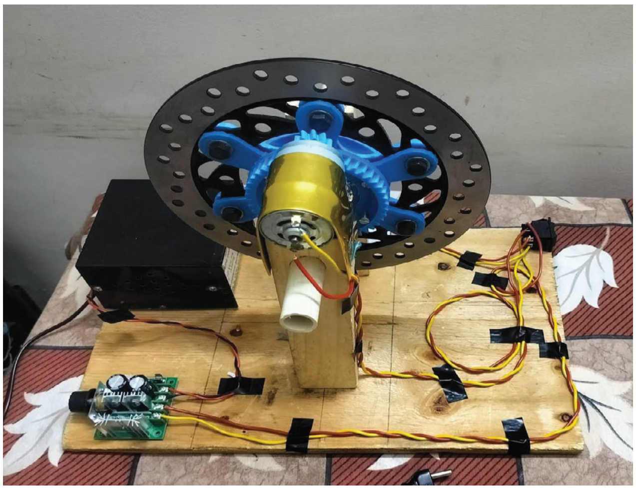

Fig. 16. Final Model

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