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SREGENERATIVE (SMART) BRAKING SYSTEM

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Abstract
Regenerative braking systems (RBS) represent a powerful approach for reclaiming energy while simultaneously curbing exhaust and brake emissions in vehicles. This technique operates by transforming the kinetic energy generated from the motor's mechanical energy into electrical energy. The resultant electrical power is then stored in the battery for future utilization. Crucially, this braking system must adhere to stringent criteria for maximum energy recuperation while ensuring safe operation within the shortest braking distances.
The aim of this study was to furnish thorough insights into regenerative energy systems. These systems offer economic advantages through fuel conservation and the mitigation of material wastage. Moreover, their adoption contributes to fostering a cleaner environment and promoting renewable energy sources, both of which are pivotal concerns on the global stage. It is evident that further extensive research is warranted in this domain.
Regenerative Braking Systems (RBS) include an effective technique to help hybrid electric buses, electric cars improve fuel efficiency while reducing exhaust emissions. The control impacts and efficiencies of the control strategies are simulated and analyzed in a typical deceleration method. When a conventional vehicle applies its brakes, kinetic energy is converted into heat as friction between the brake pads and wheels. This heat is carried away in the air stream and the energy is effectively wasted. The total ampont of energy lost in this way depends on how often, how hard and how long the brake is applied.

Keywords:
Regenerative braking System, fuel efficiency

1.Introduction
Regenerative braking involves minimizing losses and recapturing power through mechanical means. These systems utilize friction to offset the forward motion of a vehicle. When brake pads interact with the wheels or a disc linked to the axle, they generate excess heat energy. Unfortunately, this heat dissipates into the air, squandering up to 30% of the vehicle's generated power. Consequently, this cycle of friction and wasted heat gradually diminishes the car's fuel efficiency. To compensate for the energy lost during braking, the engine must exert additional power over time.Hybrid gas/electric vehicles have adopted a distinct braking approach for lower speeds. Although these cars rely on conventional brake pads when traveling at highway speeds, they employ electric motors to assist braking in stop-and-go traffic. When the driver presses the brake pedal, the electric motors switch direction. This reversal generates torque that opposes the vehicle's forward motion, gradually bringing it to a stop.But regenerative braking does more than simply stop the car. Electric motors and electric generators (such as a car's alternator) are essentially two sides of the same technology. Both use magnetic fields and coiled wires, but in different configurations. Regenerative braking systems take advantage of this duality. Whenever the electric motor of a hybrid car begins to reverse direction, it becomes an electric generator or dynamo. This generated electricity is fed into a chemical storage battery and used later to power the car at city speeds.Regenerative braking harnesses energy typically lost during braking and converts it into usable energy. However, it should not be mistaken for a perpetual motion machine. Energy loss still occurs due to factors like friction with the road surface and other system drains. While the energy recovered during braking doesn't fully replenish all the

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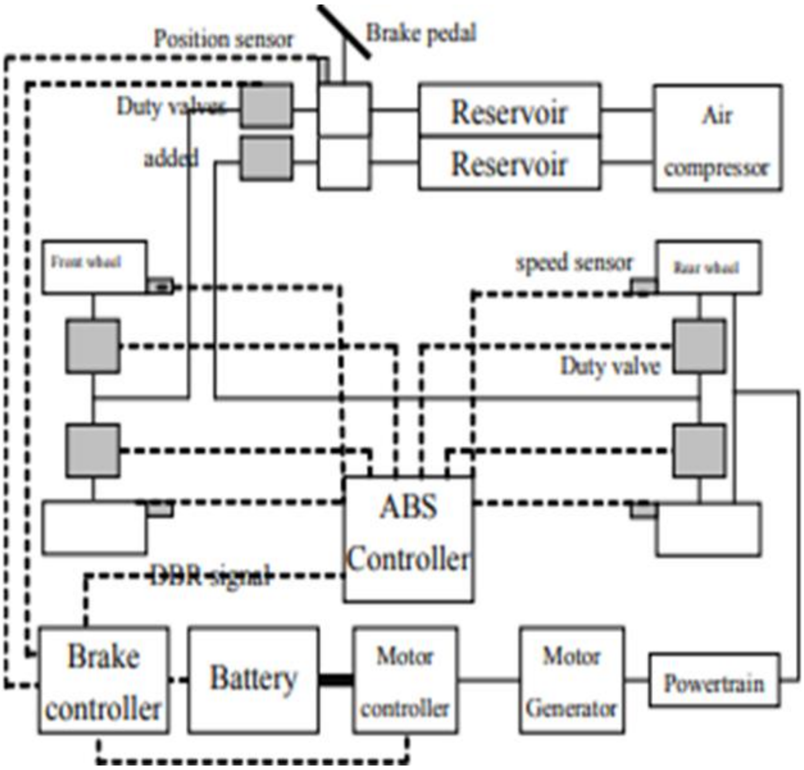
energy expended during driving, it does enhance energy efficiency and aids the main alternator.

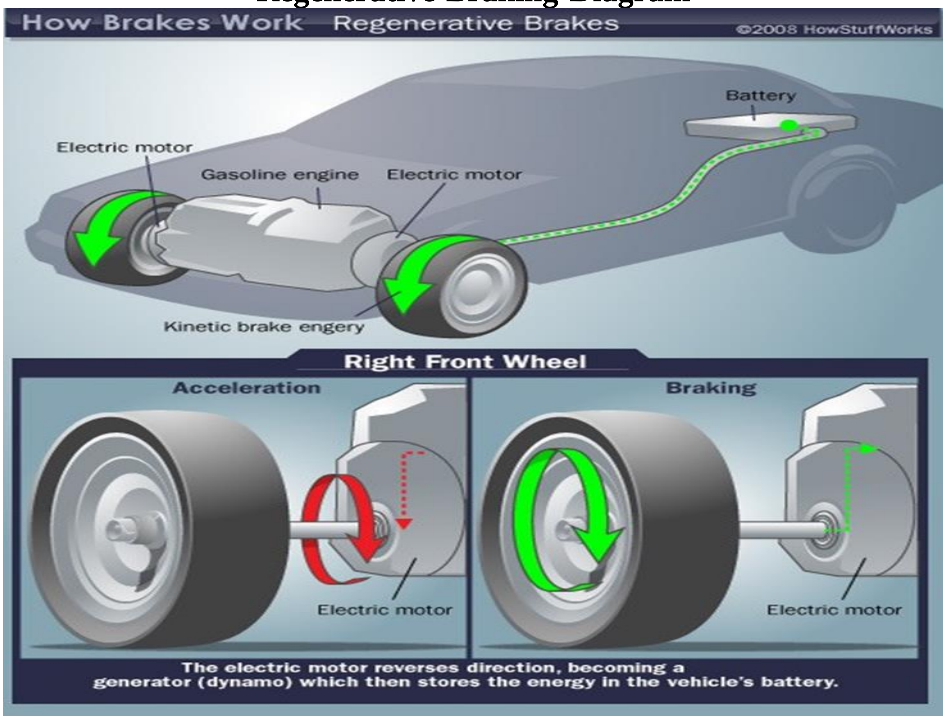
2. Literature

Regenerative Braking Diagram

This simple diagram shows how a regenerative braking system is able to recapture some of the vehicle's kinetic energy and convert it into electricity. This electricity is then used to recharge the vehicle's batteries.



Regenerative Braking Diagram



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THE MOTOR AS A GENERATOR

In electric motor-driven vehicles, regenerative braking involves utilizing the motor as a generator. When braking, the motor functions as a generator, converting kinetic energy into electrical energy. This generated output is then directed to an electrical load, effectively creating a braking effect by transferring energy to the load.

In pioneering instances, Louis Antoine Krieger (1868-1951) introduced early versions of this system through the conversion of horse-drawn cabs into front-wheel drive vehicles. The Krieger electric landaulet featured a drive motor located within each front wheel, complemented by a secondary set of parallel windings (bifilar coil) specifically designed for regenerative braking.

In 1967, an Energy Regeneration Brake was engineered for the AMC Amitron. This urban concept car ran entirely on battery power, and its batteries were replenished through regenerative braking. Consequently, this innovation extended the vehicle's range. Many modern hybrid and electric vehicles use this technique to extend the range of the battery pack. Examples include the hybrids Toyota Prius, Honda Insight, and the Vectrix electric maxi-scooter.

LIMITATIONS

Traditional friction-based braking is used with mechanical regenerative braking for the following reasons:

- The regenerative braking effect drops off at lower speeds, therefore the friction brake is still required in order to bring the vehicle to a complete halt, although malfunction of a dynamo can still provide resistance for a while. Physical locking of the rotor is also required to prevent vehicles from rolling down hills.
- The friction brake is a necessary back-up in the event of failure of the regenerative brake.
- Most road vehicles with regenerative braking only have power onsome wheels (as in a 2WD car) and regenerative braking power only appliesto such wheels, so in order to provide controlled braking under difficult conditions (such as in wet roads) friction based braking is necessary on the other wheels.
- The amount of electrical energy capable of dissipation is limited by either the capacity of the supply system to absorb this energy or on the stateof charge of the battery or capacitors. No regenerative braking effect can occur if another electrical component on the same supply system is notcurrently drawing power and if the battery or capacitors are already charged. For this reason, it is normal to also incorporate dynamic braking to absorb the excess energy.
- Under emergency braking it is desirable that the braking force exerted be the maximum allowed by the friction between the wheels and the surface.

without slipping, over the entire speed range from the vehicle's maximum speed down to zero. The maximum force available for acceleration is typically much less than this except in the case of extreme high-performance vehicles. Therefore, the power required to be dissipated by the braking system under emergency braking conditions may be many times the maximum power which is delivered under acceleration. Traction motors sized to handle the drive power may not be able to cope with the extra load and the battery may not be able to accept charge at a sufficiently high rate. Friction braking is required to absorb the surplus energy in order to allow an acceptable emergency braking performance.

For these reasons there is typically the need to control the regenerative braking and match the friction and regenerative braking to produce the desired total braking output. The GM EV-1 was the first commercial car to do this. Engineers Abraham Farag and Loren Majersik were issued two patents for this 'Brake by Wire' technology.

COMPARISON OF DYNAMIC AND REGENERATIVE BRAKES

Dynamic brakes, known as "rheostatic brakes" in the UK, differ from regenerative brakes in that they disperse electric energy as heat by directing the current through extensive arrays of variable resistors.

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Various vehicles, such as forklifts, diesel-electric locomotives, and streetcars, utilize dynamic brakes. With suitable design, the heat generated can be utilized to heat the vehicle's interior. Alternatively, if dissipation outside the vehicle is preferred, large radiator-like cowls are utilized to encase the resistor banks.
The primary drawback of regenerative brakes, in contrast to dynamic brakes, lies in the necessity to precisely align the generated current with the supply characteristics. For DC supplies, this entails tight voltage control. Only with advancements in power electronics has it become feasible to achieve this with AC supplies, where matching the supply frequency is also essential. This is particularly relevant for locomotives, where an AC supply is rectified for DC motors.
Some mountain railways have opted for 3-phase power supplies and 3-phase induction motors. This configuration ensures nearly constant speeds for all trains, as the motors rotate in sync with the supply frequency during both propulsion and braking phases.

USE IN MOTOR SPORT

A KERS flywheel

F1 teams have said they must respond in a responsible way to the world's environmental challenges, and the FIA allowed the use of 60 kW KERS in the regulations for the 2009 Formula One season. Teams began testing systems in 2008: energy can either be stored as mechanical energy (as in a flywheel) or as electrical energy (as in a battery or super capacitor). Due to high cost, FOTA teams agreed to drop KERS from the 2010 season onwards, but this is still an open issue as Williams F1 said it will use KERS in2010 and changes to the regulations must be agreed by all teams. Vodafone McLarenMercedes became the first team to win a F1 GP using a KERS equipped car when Lewis Hamilton won the Hungarian Grand Prix July 26 2009. Their second KERS equipped car finished fifth. At the following race Lewis Hamilton became the first driver to take pole position with a KERS car, his team mate qualifying second. This was also the first instance of an all KERS front row. Kimi Räikkönen won the Belgium Grand Prix August 30 2009 with his KERS equipped Ferrari. It was the first time that KERS contributed directly to a race victory, with second placed Fisichella claiming "Actually, I was quicker than Kimi. He only took me because of KERS at the beginning".

MOTORCYCLES

Harald Bartol, the racing chief of KTM, disclosed that the factory team had deployed a covert Kinetic Energy Recovery System (KERS) on Tommy Koyama's motorcycle during the 2008 season finale, the 125cc Valencian Grand Prix.

RACES

Automobile Club de l' Ouest, the organizer behind the annual 24 Hours of Le Mans event and the Le Mans Series is currently "studying specific rules for LMP1 which will be equipped with a kinetic energy recovery system." Peugeot was the first manufacturer to unveil a fully functioning LMP-1 car in the form of the 908 HY at the 2008 Auto sport 1000 km race at Silverstone.

AUTOPART MAKERS

Bosch Motorsport Service, a division of Bosch Engineering GmbH, is currently in the process of developing a Kinetic Energy Recovery System (KERS) specifically tailored for motor racing. Bosch Motorsport's hybrid systems feature an electricity storage unit, which can be a scalable lithium-ion battery or a flywheel, along with an electric motor weighing between four and eight kilograms and capable of reaching a maximum power output of 60 kW. Additionally, the KERS controller integrates power electronics, battery management, and a management system for hybrid and engine functionalities. The broader Bosch Group also offers a variety of electric hybrid systems designed for both commercial and light-duty applications.

CARMAKERS

BMW and Honda are currently conducting tests on it. During the 2008 1000 km race at Silverstone, Peugeot Sport introduced the Peugeot 908 HY, a hybrid electric version of the diesel-powered 908, equipped with KERS. Peugeot intends to enter the car in the 2009 Le Mans Series season, although it will not be eligible to earn championship points. In September 2008, Vodafone McLaren Mercedes initiated testing of their Kinetic Energy Recovery System (KERS) at the Jerez test track in anticipation of the 2009 F1 season. At that juncture, it remained uncertain whether they would adopt an electrical or mechanical system. Subsequently, in November 2008, it was revealed that Freescale Semiconductor would collaborate with McLaren Electronic Systems to enhance the KERS for McLaren's Formula One car starting from 2010. This partnership aimed to enhance McLaren's KERS technology and facilitate its integration into road car technology. Toyota, on the other hand, utilized a super capacitor for regeneration on the Supra HV-R hybrid race car, which triumphed in the 24 Hours of Tokachi race in July 2007.

USE IN COMPRESSED AIR CARS

Regenerative brakes are being used in compressed air cars to refuel the tankduring braking.

Advantages of regenerative braking sytem

- In case of regenerative braking, a part of electrical energy is returned to the supply system, so the total energy consumption for the run in electric traction is considerably reduced (about 20 to 30%). Consequently, a considerable saving in the operating cost.
- By employing regenerative braking, the wear of the brake shoes and wheel tyres is reduced to considerable extent. Therefore, their life is increased and replacement cost is decreased.
- By using the regenerative braking in the electric traction, higher value of braking retardation is obtained so that the vehicle can be brought to rest quickly and the running time is considerably reduced.
- As braking power is obtained by the regenerative braking, only a small amount of brake dust is produced when mechanical brakes are applied.
- As the regenerative braking provides high braking retardation, so high speeds of the train are possible while going down the gradients or slopes.
- If regenerative braking is provided, then propulsion of heavier trains on gradients is possible without dividing them into sections with speed and safety.

Working Principle of Regenerative Braking System

Regenerative braking is a braking technique that replenishes the battery by converting the motor's mechanical and kinetic energy into electrical energy. When engaged, the vehicle's engine decelerates when moving uphill. As the brake pedal is pressed, the vehicle slows down, causing the motor to operate in reverse. When operating in the opposite direction, the engine acts as a generator and converts torque energy into electrical energy. In this way, fuel consumption and emissions are reduced. In high-speed vehicles, the braking force is lo wer, and therefore does not adversely affect the traffic flow [01]. The new electric-hydraulic powertrain is a parallel hybrid system that includes a traction motor, battery pack, hydraulic pump / motor (secondary component), hydraulic accumulator, reservoir, and a set of hydraulic valves. The hydraulic circuit includes the drive circuit and the drain circuit. The drive circuit consists of a cartridge valve, a one-way valve, and a two-position four-way valve. When the vehicle is braking, the valve is shifted to the left; this directs the oil from the reservoir to flow towards the accumulator using the secondary component pump / motor. The secondary component operates in pump mode, using the kinetic energy of the vehicle to pressurize the oil in the reservoir to flow into the accumulator. The energy isstored in the accumulator and the vehicle slows down. The hydraulic system works in the regenerative braking mode [02]. These brakes work very effectively in urban braking situations. The brake system and control sensors are programmed to control all of the vehicle motors. The brake control sensor calculates the electricity to be generated and the rotational force to be fed to the batteries by monitoring the speed and torque of the wheel. During braking, the brake control sensor controls the electrical energy generated by the motor and directs it to the batteries [03]

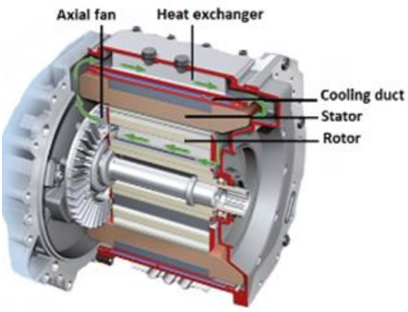
Parts of regenerative braking system

As the Regenerative Braking is a type of Electric Braking System; mostly it consists electrical and electronic devices or parts. So, the parts of Regenerative Braking System are[04]

- Electric Traction Motor
- Battery Pack
- Hydraulic Pump
- Accumulator
- Hydraulic Circuit
- Reservoir
- Hydraulic Valves
- Electronic Control Unit (ECU)

Electric traction motor

A traction motor is an electric motor designed for propelling various types of vehicles, including locomotives, electric or hydrogen-powered vehicles, and electric multiple unit trains. These motors find application in electrically driven railway vehicles like electric multiple units, as well as in other electric vehicles such as electric milk floats, trolleybuses, elevators, roller coasters, and conveyor systems. They are also utilized in vehicles featuring electrical transmission systems like diesel-electric locomotives, electric hybrid vehicles, and battery electric vehicles. [05]



Traction Motor

An electric vehicle battery (EVB), also referred to as a traction battery, serves as the rechargeable power source for electric motors in battery electric vehicles (BEVs) or hybrid electric vehicles (HEVs). Unlike starting, lighting, and ignition (SLI) batteries, EV batteries are predominantly lithium-ion batteries engineered for a high power-to-weight ratio and energy density. The preference for smaller,

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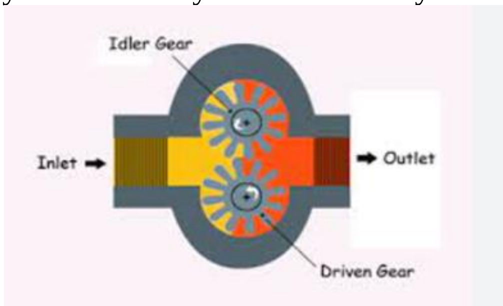
lighter batteries is driven by their ability to reduce vehicle weight, thereby enhancing performance. [06]

Battery Pack

A hydraulic pump serves as a mechanical power source that transforms mechanical energy into hydraulic energy, specifically hydrostatic energy, encompassing flow and pressure. These pumps find application in hydraulic drive systems and may exist in either hydrostatic or hydrodynamic forms**.**



Hydraulic Pump

An electronic control unit (ECU), alternatively referred to as an electronic control module (ECM), is an integrated system within automotive electronics responsible for managing one or multiple electrical systems or subsystems in a vehicle, such as cars or other motor vehicles.

ECU

3.Conclusion

This study provides insights into the principles and characteristics of regenerative braking systems. Numerous studies in automation, electro mechanics, and construction have been conducted to enhance the efficiency of recovered energy and lower operating expenses in this domain. Recognizing that a significant portion of global economic losses stems from mechanical wear, the significance of regenerative braking systems has gained greater acknowledgment. Enhancements in safety, comfort, and economic efficiency can be achieved through the advancement of regenerative braking systems. While currently utilized to a limited extent in electric vehicles, these systems can also be integrated into conventional braking mechanisms or other motion control systems. Upon widespread adoption, significant economic benefits can be realized through reduced mechanical losses and energy conservation facilitated by the recovery of electrical energy. Moreover, the utilization of regenerative braking can mitigate vehicle emissions stemming from conventional brake wear, thereby contributing to environmental preservation and human health. Consequently, these systems underscore the importance of energy recovery, reduced energy consumption, cost reduction, and the promotion of clean air. Hence, there is a pressing need for comprehensive research in the field of regenerative braking systems, with subsequent dissemination of findings to policymakers and researchers.

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