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REGENERATIVE BRAKING SYSTEM IN ELECTRIC VEHICLE

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Abstract. Regenerative braking is a mechanism found on most hybrid and full-electric vehicles. It captures the kinetic energy from braking and converts it into the electrical power that charges the vehicle's high voltage battery. Regenerative braking also slows the car down, which assists the use of traditional brakes.

In a conventional braking system, a car slows down due to friction between the brake pads and rotors. But this system is highly inefficient when it comes to conserving energy. Nearly all of the kinetic energy propelling your car forward is lost as heat when you apply the brakes. That's a lot of wasted energy. Regenerative braking solves this problem by recapturing upwards of 70% of the kinetic energy that would otherwise be lost during braking. The amount of energy recovered depends on your car model and driving behavior.

Regenerative braking turns kinetic energy into electricity by reversing the process that drives the car forward. In electric cars, the drive train is powered by a battery pack that powers a motor (or motors), creating torque–rotational force–on the wheels. In other words, electrical energy from the battery becomes mechanical energy that spins the wheels.

With regenerative braking, the energy from your spinning wheels is used to reverse the direction of electricity - from the electric motor(s) to the battery. All you have to do is remove your foot from the accelerator or, in some cases, press the brake pedal to activate regenerative braking. The electric motor not only acts as an electric generator, but it also helps slow your car down because energy is consumed by the wheels as they rotate the shaft in the electric motor.

Keywords: Regenerative Braking System

Introduction

Regenerative Braking System is the way of slowing vehicle by using the motors as brakes. Instead of the surplus energy of the vehicle being wasted as unwanted heat, the motors act as generators and return some of it to the overhead wires as electricity. The vehicle is primarily powered from the electrical energy generated from the generator, which burns gasoline. This energy is stored in a large battery, and used by an electric motor that provides motive force to the wheels. The regenerative braking taking place on the vehicle is away to obtain more efficiency, instead of converting kinetic

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energy to thermal energy through frictional braking, the vehicle can convert a good fraction of its kinetic energy back into charge in the battery, using the same principle as an alternator. Therefore, if you drive long distance without braking, you'll be powering the vehicle entirely from gasoline. Regenerative Braking System comes into its own when you're driving in the city, and spending a good deal of your time braking. You will still use more fuel in the city for each mile you drive than on the highway, though. Thermodynamics tells us that all inefficiency comes from heat generation. For instance, when you brake, the brake pedals heat up and a quantity of heat, or energy, is lost to the outside world. Friction in the engine produces heat in the same way .In most electric and hybrid electric vehicles on the road today, this is accomplished by operating the traction motor as a generator, providing braking torque to the wheels and recharging the traction batteries. The energy provided by regenerative braking can then be used for propulsion or to power vehicle accessories. In Regenerative braking system instead of wasting the kinetic energy of vehicle in the form of heat it is converted into electrical energy to be stored in batteries and capacitors or as mechanical energy of a flywheel having large moment of inertia. In this way a large proportion of energy of vehicle is saved

1.1 Need for Regenerative Brakes

The regenerative braking system delivers a number of significant advantages over a car that only has friction brakes. In low-speed, stop- and-go traffic where little deceleration is required; the regenerative braking system can provide the majority of the total braking force. This vastly improves fuel economy with a vehicle, and further enhances the attractiveness of vehicles using regenerative braking for city driving. At higher speeds, too, regenerative braking has been shown to contribute to improved fuel economy – by as much as 20%.

Consider a heavy loaded truck having very few stops on the road. It is operated near maximum engine efficiency. The 80% of the energy produced is utilized to overcome the rolling and aerodynamic road forces. The energy wasted in applying brake is about 2%. Also its brake specific fuel consumption is 5%.

Now consider a vehicle, which is operated in the main city where traffic is a major problem here one has to apply brake frequently. For such vehicles the wastage of energy by application of brake is about 60% to 65%.

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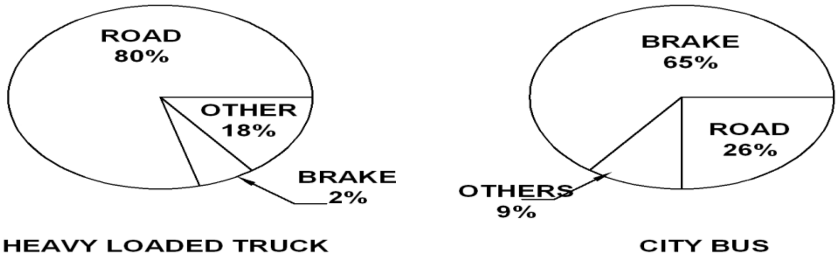

Fig. A - Graphical Representation of Energy Usage of Two Vehicles

2. Idea of Regenerative Brakes

Concept of this regenerative brake is better understood from bicycle fitted with Dynamo. If our bicycle has a dynamo (a small electricity generator) on it for power the lights, we'll know it's harder to peddle when the dynamo is engaged than when it's switched off. That's because some of our peddling energy is being "stolen" by the dynamo and turned into electrical energy in the lights. If we're going along at speed and we suddenly stop peddling and turn on the dynamo, it'll bring us to a stop more quickly than we would normally, for the same reason: it's stealing our kinetic energy. Now imagine a bicycle with a dynamo that's 100 times bigger and more powerful. In theory, it could bring our bike to a halt relatively quickly by converting our kinetic energy into electricity which we could store in a battery and use again later. And that's the basic idea behind regenerative brakes. Electric trains, cars, and other electric vehicles are powered by electric motors connected to batteries. When we're driving along, energy flows from the batteries to the motors, turning the wheels and providing us with the kinetic energy we need to move. When we stop and hit the brakes, the whole process goes into reverse: electronic circuits cut the power to the motors. Now, our kinetic energy and momentum makes the wheels turn the motors, so the motors work like generators and start producing electricity instead of consuming it. Power flows back from these motor-generators to the batteries, charging them up. So a good proportion of the energy we lose by braking is returned to the batteries and can be reused when we start off again. In practice, regenerative brakes take time to slow things down, so most vehicles that use them also have ordinary (friction) brakes working alongside (that's also a good idea in case the regenerative brakes fail).That's one reason why regenerative brakes don't save 100 percent of our braking energy.

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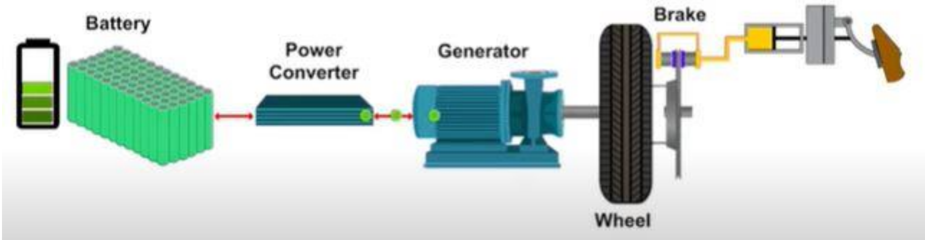

Fig. B - Basic Idea of Regenerative Brakes

3. Basic Elements of the System

There are four elements required which are necessary for the working of regenerative braking system, these are:)

(1) Batteries

With this system as we know, the electric motor of a car becomes a generator when the brake pedal is applied. The kinetic energy of the car is used to generate electricity that is then used to recharge the batteries. With this system, traditional friction brakes must also be used to ensure that the car slows down as much as necessary. Thus, not all of the kinetic energy of the car can be harnessed for the batteries because some of it is "lost" to waste heat. Some energy is also lost to resistance as the energy travels from the wheel and axle, through the drive train and electric motor, and into the battery.

When the brake pedal is depressed, the battery receives a higher charge, which slows the vehicle down faster. The further the brake pedal is depressed, the more the conventional friction brakes are employed.

The motor/generator produces AC, which is converted into DC, which is then used to charge the Battery Module. So, the regenerative systems must have an electric controller that regulates how much charge the battery receives and how much the friction brakes are used.

(2) Fly Wheels

In this system, the translational energy of the vehicle is transferred into rotational energy in the flywheel, which stores the energy until it is needed to accelerate the vehicle.

The benefit of using flywheel technology is that more of the forward inertial energy of the car can be captured than in batteries, because the flywheel can be engaged even during relatively short intervals of braking and acceleration. In the case of batteries, they are not able to accept charge at these rapid intervals, and thus more energy is lost to friction.

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Another advantage of flywheel technology is that the additional power supplied by the flywheel during acceleration substantially supplements the power output of the small engine that hybrid vehicles are equipped with.

(3) Controller

An "ON-OFF" engine control system is used. That means that the engine is "ON" until the energy storage unit has been reached the desired charge capacity and then is decoupled and stopped until the energy storage unit charge fall below its minimum requirement.

4. Different Types of Regenerative Braking System

4.1 Electric Regenerative Braking

In an electric system which is driven only by means of electric motor the system consists of an electric motor which acts both as generator and motor. Initially when the system is cruising the power is supplied by the motor and when the there is a necessity for braking depending upon driver's applied force on the brake pedal the electronic unit controls the charge flowing through the motor and due to the resistance offered motor rotates back to act as a generator and the energy is energy is stored in a battery or bank of twin layer capacitors for later use. In hybrid system, motor will be coupled to another power source normally. I. C. engines is shown in the fig (1).

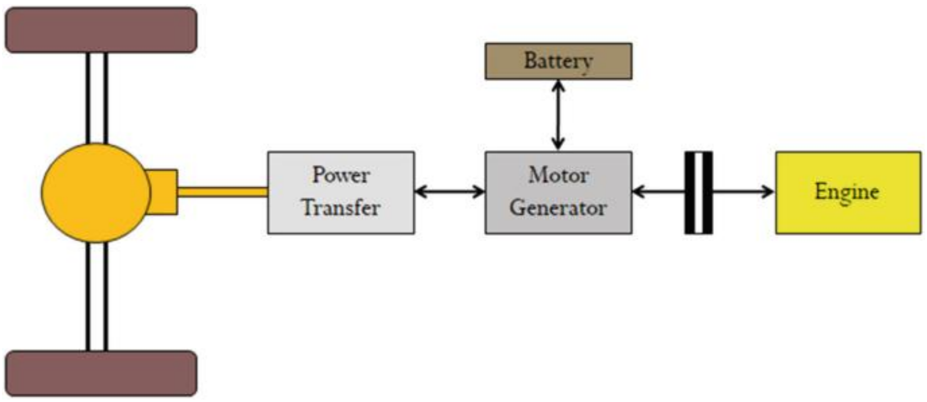

Fig. 1

4.2 Hydraulic Regenerative Brakes

Hydrostatic Regenerative Braking (HRB) system uses electrical/electronic components as well as hydraulics to improve vehicle fuel economy. An alternative regenerative braking system is being developed by the Ford Motor Company and the Eaton Corporation. It's called Hydraulic Power Assist or HPA. With HPA, when the driver steps on the brake, the vehicle's kinetic energy is used to

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power a reversible pump, which sends hydraulic fluid from a low pressure accumulator (a kind of storage tank) inside the vehicle into a high pressure accumulator. The pressure is created by nitrogen gas in the accumulator, which is compressed as the fluid is pumped into the space the gas formerly occupied. This slows the vehicle and helps bring it to a stop. The fluid remains under pressure in the accumulator until the driver pushes the accelerator again, at which point the pump is reversed and the pressurized fluid is used to accelerate the vehicle, effectively translating the kinetic energy that the car had before braking into the mechanical energy that helps get the vehicle back up to speed. It's predicted that a system like this could store 80 percent of the momentum lost by a vehicle during deceleration and use it to get the vehicle moving again.

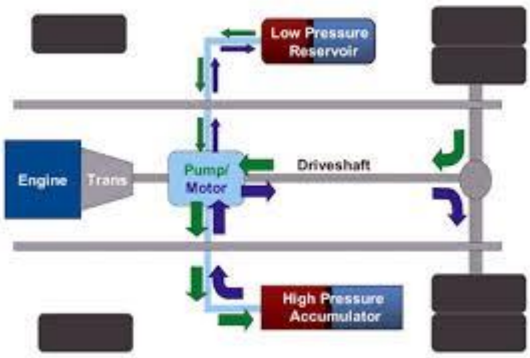

Fig..2

5. **Advantages and Disadvantages of Regenerative Braking**
1. **Advantages of Regenerative Braking**

As you can imagine, capturing and reusing more energy from braking has real benefits for the efficiency of your vehicle. Plus, it means less wear and tear on your brakes. Here are the biggest advantages of regenerative braking:

- **Brake Pads & Rotors May Last Longer**
  Even though regenerative braking provides a lot of stopping force on its own, EVs and hybrids also come with conventional hydraulic brakes. However, since regenerative braking does much of the work while slowing the vehicle, the brake pads and rotors are used much less frequently. As a result, they typically last much longer between servicing, which can help drivers save on maintenance costs. That being said, it’s still important to have your brakes inspected regularly, and routine checks may be required as part of your manufacturer's suggested maintenance schedule. Just bring your hybrid or electric vehicle into Tires Plus for a quick and convenient inspection.
- **Extended Range Possibilities for EVs**

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Capturing braking energy and sending it right back to your EV's battery pack can extend your driving range. Estimations show that regenerative braking can potentially add hundreds of miles of electric driving range throughout the year. That means less time spent charging and more time getting where you need to go. When charging stations are still far and few between in many areas, every mile counts. Plus, when you plug into the electric grid less often, you help reduce emissions from coal and gas-powered electricity suppliers.

- **Better Fuel Efficiency for Hybrids**

  While hybrids still have internal combustion engines under the hood, they're designed to use their electric motor as much as possible. Regenerative braking helps keep the battery pack charged, so drivers don't have to rely on their engines as often, helping them reduce fuel consumption and save money.

2. **Disadvantages of a Regenerative Braking System**

While the positives of regenerative braking definitely outweigh the negatives, no technology is perfect. Here are a few instances where regenerative braking falls short:

- **May Be Less Effective at Lower Speeds**

  Traveling at slower speeds means your vehicle has less kinetic energy and requires less braking force. As a result, the regenerative braking system is fed less energy and does not supply the battery pack with much charge. Some vehicle manufacturers also feel that coasting may outweigh the benefits of regenerative braking in some situations.

- **Brake Pedal May Feel Different**

  One thing you want to be sure of while driving is that your brake pedal works. While the brake pedals on hybrid and electric vehicles certainly function, they may feel different in a way you're not used to. You may experience momentary unresponsiveness or a pedal that doesn't compress as smoothly as you expect. In some cases, you may need to modulate the pedal differently. The good news is that this change in brake pedal feel is less of a problem than it used to be. Newer hybrid and EV models have more responsive brake pedals that feel the same as any set of conventional brakes.

- **Potentially Less Stopping Power**

  While regenerative braking performs just fine in most braking situations where you gradually come to a stop, it may not provide the same level of stopping force that conventional brakes do. This means hybrid and EV drivers may have to press harder on the brakes to achieve the same effectiveness. However, this problem is also improving with

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newer regenerative braking systems. In more recent car models, you may not notice a difference in stopping power at all.

6. Comparisons

6.1 Advantages of Regenerative Braking over Conventional Braking

Energy Conservation

The flywheel absorbs energy when braking via a clutch system slowing the car down and speeding up the wheel. To accelerate, another clutch system connects the flywheel to the drive train, speeding up the car and slowing down the flywheel. Energy is therefore conserved rather than wasted as heat and light which is what normally happens in the contemporary shoe/disc system.

Wear Reduction

An electric drive train also allows for regenerative breaking which increases Efficiency and reduces wear on the vehicle brakes. In regenerative braking, when the motor is not receiving power from the battery pack, it resists the turning of the wheels, capturing some of the energy of motion as if it were a generator and returning that energy to the battery pack. In mechanical brakes; lessening wear and extending brake life is not possible. This reduces the use of use the brake.

Fuel Consumption

The fuel consumption of the conventional vehicles and regenerative braking system vehicles was evaluated over a course of various fixed urban driving schedules. The results are compared as shown in figure. Representing the significant cost saying to its owner, it has been proved the regenerative braking is very fuel-efficient. The Delhi Metro saved around 90,000 tons of carbon dioxide (CO_2) from being released into the atmosphere by regenerating 112,500 megawatt hours of electricity through the use of regenerative braking systems between 2004 and 2007. It is expected that the Delhi Metro will save over 100,000 tons of CO_2 from being emitted per year once its phase II is complete through the use of regenerative braking. The energy efficiency of a conventional car is only about 20 percent, with the remaining 80 percent of its energy being converted to heat through friction. The miraculous thing about regenerative braking is that it may be able to capture as much as half of that wasted energy and put

6.2 Comparison of Dynamic Brakes and Regenerative Brakes

Dynamic brakes ("rheostat brakes" in the UK), unlike regenerative brakes, dissipate the electric energy as heat by passing the current through large banks of variable resistors. Vehicles that use dynamic brakes include forklifts, Diesel-electric locomotives, and streetcars. This heat can be used to warm the vehicle interior, or dissipated externally by large radiator-like cowls to house the resistor banks.

The main disadvantage of regenerative brakes when compared with dynamic brakes is the need to closely match the generated current with the supply characteristics and increased maintenance cost of the lines. With DC supplies, this requires that the voltage be closely controlled. Only with the development of power electronics has this been possible with AC supplies, where the supply frequency must also be matched (this mainly applies to locomotives where an AC supply is rectified for DC motors). A small number of mountain railways have used 3-phase power supplies and 3-phase induction motors. This results in a near constant speed for all trains as the motors rotate with the supply frequency both when motoring and braking.

7. Conclusion

The beginning of the 21st century could very well mark the final period in which internal combustion engines are commonly used in cars. Already automakers are moving toward alternative energy carriers, such as electric batteries, hydrogen fuel and even compressed air. Regenerative braking is a small, yet very important, step toward our eventual independence from fossil fuels. These kinds of brakes allow batteries to be used for longer periods of time without the need to be plugged into an external charger. These types of brakes also extend the driving range of fully electric vehicles. In fact, this technology has already helped bring us cars like the Tesla Roadster, which runs entirely on battery power. Sure, these cars may use fossil fuels at the recharging stage -- that is, if the source of the electricity comes from a fossil fuel such as coal -- but when they're out there on the road, they can operate with no use of fossil fuels at all, and that's a big step forward. When you think about the energy losses incurred by battery-electric hybrid systems, it seems plausible to reason that efficient flywheel hybrids would soon become the norm. But of course it’s not quite so black and white, and further analysis shows that a combination of battery-electric and flywheel energy storage is probably the ideal solution for hybrid vehicles. As designers and engineers perfect regenerative braking systems, they will become more and more common. All vehicles in motion can benefit from utilizing regeneration to recapture energy that would otherwise be lost.

References

[1] Cibulka J. Kinetic energy recovery system by means of flywheel energy storage. Advanced engineering. 3. 2009

[2] howstuffswork.com

[3] Hewko L. O. Automotive traction drive CVTs – An overview. SAE paper 861355

[4] Juan W. Dixon, Micah Ortúzar, Eduardo Wiechmann. Regenerative Braking for an Electric Vehicle Using Ultracapacitors and a Buck-Boost Converter

ISBN Number: 978-93-95305-78-5
[5] Chris Brockbank. Development of Full-Toroidal Traction Drives in Flywheel Based Mechanical Hybrids”

[6] Ziqiang Chen, Jiaxi Qiang, Jianhui He, Lin Yang. Intelligent Regenerative Braking Control of Hybrid Buses

[7] S. J. Clegg. A Review of Regenerative Braking System. Institute of Transport Studies, University of Leeds, Working paper of 471, 1996

[8] Regenerative braking boosts green credentials. Railway Gazette International. 2 July 2007

[9] Omkar Khatavkar " Regenerative Braking System" IJIRMPS | Volume 9, Issue 4, 2021 ISSN: 2349-7300