SEMINAR REPORT ON

“REGENERATIVE BRAKING”

Submitted by

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ABSTRACT

As the basic law of Physics says ‘energy can neither be created nor be destroyed it can only be converted from one form to another’. During huge amount of energy is lost to atmosphere as heat. It will be good if we could store this energy somehow which is otherwise getting wasted out and reuse it next time we started to accelerate. Regenerative braking refers to a system in which the kinetic energy of the vehicle is stored temporarily, as an accumulative energy, during deceleration, and is reused as kinetic energy during acceleration or running. 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. Regenerative braking is a way to extend range of the electric vehicles. In many hybrid vehicles cases, this system is also applied hybrid vehicles to improve fuel economy.
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INTRODUCTION

Brakes are employed to stop or retard the motion of any moving body. Thus, in automobiles the brakes are having the most important function to perform.

In conventional braking system the motion is retarded or stopped by absorbing kinetic energy by friction, by making the contact of the moving body with frictional rubber pad (called brake liner) which causes the absorption of kinetic energy, and this is wasted in form of heat in surroundings. Each time we brake, the momentum of vehicle is absorbed that it has gained by it and to re-accelerate the vehicle we have to start from the scratch to redevelop that momentum by using the more power from an engine. Thus, it will ultimately result in huge waste of energy.

As the basic law of Physics says ‘energy can neither be created nor be destroyed it can only be converted from one form to another’. It will be good if we could store this energy somehow which is otherwise getting wasted out and reuse it next time we started to accelerate. That's the basic concept of regenerative ("regent") brakes, which provide braking for the system when needed by converting the available energy to some usable form. These are widely used in electric trains and the latest electric cars. Regenerative brake is an energy recovery mechanism which slows a vehicle by converting its kinetic energy into another form, which can be either used immediately or stored until needed. Thus, the generated electricity during the braking is fed back into the supply system (in case of electric trains), whereas in battery electric and hybrid electric vehicles, the energy is stored in a battery or bank of capacitors for later use. Energy may also be stored by compressing air or in a rotating flywheel.

An Energy Regeneration Brake was developed in 1967 for the AMC Amitron. This was a completely battery powered urban concept car whose batteries were recharged by regenerative braking, thus increasing the range of the automobile.

Many modern hybrid and electric vehicles use this technique to extend the range of the battery pack. Examples include the Toyota Prius, Honda Insight, the Vectrix electric maxi-scooter, and the Chevrolet Volt.

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%.

![Graphical Representation of Energy usage of two vehicles](image_url)

**Fig (a): Graphical Representation of Energy usage of two vehicles**
BASIC 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 powering 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.
2.1 The Motor as a generator

Vehicles driven by electric motors use the motor as a generator when using regenerative braking, it is operated as a generator during braking and its output is supplied to an electrical load; the transfer of energy to the load provides the braking effect.

Regenerative braking is used on hybrid gas/electric automobiles to recoup some of the energy lost during stopping. This energy is saved in a storage battery and used later to power the motor whenever the car is in electric mode.
CHAPTER 3

BASIC ELEMENTS OF THE SYSTEM

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

3.1 Energy Storage Unit (ESU):

The ESU performs two primary functions

1) To recover & store braking energy
2) To absorb excess engine energy during light load operation

The selection criteria for effective energy storage include:

I. High specific energy storage density
II. High energy transfer rate
III. Small space requirement

The energy recaptured by regenerative braking might be stored in one of three devices:

- An electrochemical battery
- A flywheel
- Compressed air

➤ 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.

- **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. 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.

### 3.2 Continuously Variable Transmission (CVT):

The energy storage unit requires a transmission that can handle torque and speed demands in a steeples manner and smoothly control energy flow to and from the vehicle wheels.

### 3.3 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.

### 3.4 Regenerative Brake Controllers

Brake controllers are electronic devices that can control brakes remotely, deciding when braking begins ends, and how quickly the brakes need to be applied.
During the braking operation, the brake controller directs the electricity produced by the motor into the batteries or capacitors. It makes sure that an optimal amount of power is received by the batteries, but also ensures that the inflow of electricity isn't more than the batteries can handle.

The most important function of the brake controller, however, may be deciding whether the motor is currently capable of handling the force necessary for stopping the car. If it isn't, the brake controller turns the job over to the friction brakes. In vehicles that use these types of brakes, as much as any other piece of electronics on board a hybrid or electric car, the brake controller makes the entire regenerative braking process possible.
CHAPTER 4

DIFFERENT TYPES OF REGENERATIVE BRAKING

Based on the mode of storage of energy some of the system developed can be listed they are:-

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 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 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 as shown in the fig (1)

The main components of this system

- Engine
- Motor/Generator
- Batteries
- Electronic control system

During acceleration, the Motor/generator unit acts as an electric motor drawing electrical energy from the batteries to provide extra driving force to move the car as (Shown in fig 2). With this help from the motor, the car's internal combustion engine that is smaller and with lower peak power can achieve high efficiency. During braking electric supply from the battery is cut off by the electronic system. As the car is still moving forward, the Motor/Generator unit acts as an electric generator converting car's kinetic energy into electrical and store in the batteries (shown in fig 3) for later use.

![Fig (2) showing energy consumption from battery.](image)
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 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.

Bosch Rexroth has a regenerative braking system that does not require a hybrid vehicle. In fact, it does not involve electrical storage. The Hydrostatic Regenerative Braking (HRB) system is intended for commercial vehicles and mobile equipment. The company says that initial measurements show that the HRB system reduces the fuel consumption in these vehicles by up to 25%.

In the HRB system, braking energy is converted to hydraulic pressure and stored in a high-pressure hydraulic accumulator. When the vehicle accelerates, the stored hydraulic energy is applied to the transmission reducing the energy that the combustion engine has to provide. An electronic controller and a hydraulic valve manifold control the process.
At present, these hydraulic regenerative brakes are noisy and prone to leaks; however, once all of the details are ironed out, such systems will probably be most useful in large trucks.

4.3. Fly Wheels

Regenerative brakes may seem very hi-tech, but the idea of having "energy-saving Reservoirs" in machines is nothing new. Engines have been using energy-storing devices called flywheels virtually since they were invented.

The basic idea is that the rotating part of the engine incorporates a wheel with a very heavy metal rim, and this drives whatever machine or device the engine is connected to. It takes much more time to get a flywheel-engine turning but, once it's up to speed, the flywheel stores a huge amount of rotational energy. A heavy spinning flywheel is a bit like a truck going at speed: it has huge momentum so it takes a great deal of stopping and changing its speed takes a lot of effort. That may sound like a drawback, but it's actually very useful. If an engine supplies power erratically, the flywheel compensates, absorbing extra power and making up for temporary lulls, so the machine or equipment it's connected to is driven more smoothly.

It's easy to see how a flywheel could be used for regenerative braking. In something like a bus or a truck, you could have a heavy flywheel that could be engaged or disengaged from the transmission at different times. You could engage the flywheel every...
time you want to brake so it soaked up some of your kinetic energy and brought you to a
halt. Next time you started off, you'd use the flywheel to return the energy and get you
moving again, before disengaging it during normal driving. The main drawback of using
flywheels in moving vehicles is, of course, their extra weight. They save you energy by
storing power you'd otherwise squander in brakes, but they also cost you energy because
you have to carry them around all the time.

The transfer of energy in both directions (captured from the driveline during coasting and
braking, and released to the driveline for boost) is managed through a CVT (Continuously
Variable Transmission) gear box. Packaged inside a single housing is a shaft-
mounted flywheel that is connected via a chain/gear or belt/pulley drive to a series of
discs and rollers (the CVT). During braking and coasting, the flywheel spools-up
(accelerates as it spins) and absorbs a storehouse of otherwise wasted energy (heat from
friction brakes). During power delivery, as the vehicle begins to accelerate, the pent-up
energy in the flywheel is released and it turns the shaft. The rollers within the CVT can
change position across the discs and either retard or augment the torque of the spinning
flywheel shaft much like a conventional step-up or step-down gear box. This “gearing” is
necessary, because unlike aircraft, and to a certain extent watercraft, which travel at a
relatively constant load and speed, earth-bound vehicles travel at regularly and greatly
varying speeds and loads as they negotiate traffic and topography. It is this variable
output velocity that allows for smooth power transmission from the flywheel to the
driveline as the vehicle travels over the roadway.

Advanced transmissions that incorporate hi-tech flywheels are now being used as
regenerative systems in such things as formula-1 cars, where they're typically referred to
as Kinetic Energy Recovery Systems (KERS).

**Pros of flywheel systems**

- **Compact weight and size** -- The entire system (the CVT, the flywheel and
  the housing) is roughly half the weight and packaging of a battery hybrid
  system.
• **Twice as efficient** -- Battery-electric structures lose kinetic potential during the conversion of energy from mechanical to electrical to chemical, and then back again. It’s a fundamental of the Second Law of Thermodynamics: transforming energy from one form to another introduces losses. Battery-electrics are approximately 34 percent efficient. Flywheel drives are all mechanical and suffer no conversion losses. Most of the energy loss that does occur comes from normal friction between moving parts. These systems are about 70 percent efficient.

• **Lower cost** -- Smaller size and weight and reduced complexity make these arrangements about one quarter the cost of a battery-electric system.

4.4. Use in compressed air

Regenerative brakes could be employed in compressed air cars to refill the air tank during braking. By absorbing the kinetic energy (necessary for braking), using the same for compressing the air and reuse these compressed air while powering the car.

4.5. Regenerative Braking Using Nitilon Spring

From fig it is clear that while braking the kinetic energy is stored in form of potential energy in spring. When the system actually demands for the acceleration this potential energy stored is given back to the wheels to power them.
CHAPTER 5

APPLICATIONS

Some of vehicles using regenerative brake:-

Fig (f): Toyota Prius

Fig.(g): Ford FUSION
Fig.(h): Tesla Roadster Electric Car

Fig(i): Truck using Hydraulic Regenerative Brake (HRB)

Fig(j): Vectrix Electric Maxi-Scooter
CHAPTER 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 (CO₂) 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 CO₂ 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 it back to work. This could reduce fuel consumption by 10 to 25 percent. Hydraulic regenerative braking systems could provide even more impressive gains, potentially reducing fuel use by 25 to 45 percent.

**Braking is not total loss:**

Conventional brakes apply friction to convert a vehicle’s kinetic energy into heat. In energy terms, therefore, braking is a total loss: once heat is generated, it is very difficult to reuse. The regenerative braking system, however, slows a vehicle down in a different way.
6.2 Comparison of Dynamic brakes and Regenerative brakes

Dynamic brakes ("rheostatic 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.
6.3 Why Regenerative Brakes are assisted with the Frictional Brake??

Traditional friction-based braking is used in conjunction 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. 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 on some wheels (as in a two-wheel drive car) and regenerative braking power only applies to 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 state of charge of the battery or capacitors. No regenerative braking effect can occur if another electrical component on the same supply system is not currently 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.
CHAPTER 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.
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