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Regenerative Braking System

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Abstract:

In recent years, increased concerns over the impact of the conventional car (ICE – Internal Combustion Engine) on the environment have led to improvement and advancement in the Electric Vehicle (EV).The need to improve overall efficiency of the vehicle has led to the design of the regenerative braking system (RBS). The RBS will be used to convert the car's mechanical energy and also the heat that would have been lost during braking into electrical energy during braking. The 2 most important aspects of the design have been listed below. Power generation: In electric vehicles during braking the motor which is used to run the vehicle transforms in to a generator & the power generated is again sent to the battery and is used to run the vehicle. Braking: In RBS, conventional braking is avoided & the required breaking force is generated in the motor itself which is used to run the vehicle. When the motor transforms in to a generator, due to the load acting on the motor there will be a stopping force acted in the motor and finally the vehicle gets stopped. Finally we analysis how much amount of energy we are able to save through RBS & how efficiently we are able to generate the braking force, which in turn leads to increase in overall efficiency of the Electric vehicle (EV).

I. 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

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reuse it next time we started to accelerate. That's the basic concept of regenerative brakes, which provide braking for the system when needed by converting the available energy to some usable form.

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%.

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.

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. It is based up on the Faraday’s first law.

In 1831, Michael Faraday, an English physicist gave one of the most basic laws of electromagnetism called Faraday's law of electromagnetic induction. This law explains the working principle of most of the electrical motors, generators, electrical transformers and inductors. This law shows the relationship between electric circuit and magnetic field. Faraday performs an experiment with a magnet and coil. During this experiment, he found how emf is induced in the coil when flux linked with it changes.

Main principle:

Any change in the magnetic field of a coil of wire will cause an emf to be induced in the coil. This emf induced is called induced emf and if the conductor circuit is closed, the current will also circulate through the circuit and this current is called induced current.

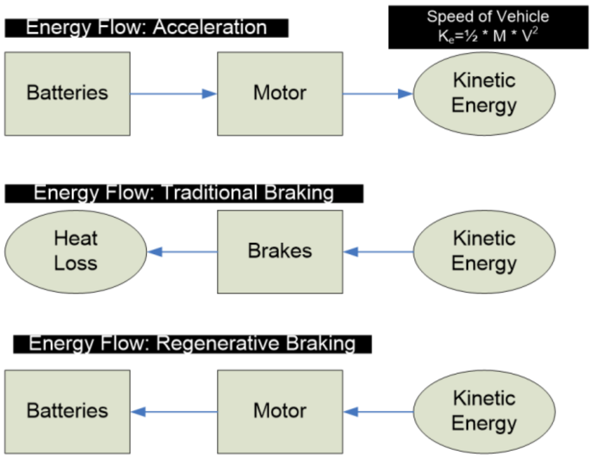

Fig 1: Energy Flow Chart

II. DIFFERENT TYPES OF REGENERATIVE BRAKING SYSTEM:

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

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

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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

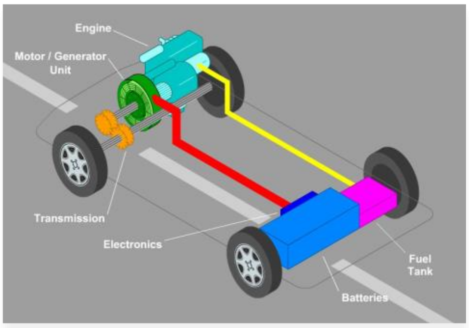

Fig 2: layout of hybrid vehicle.

The main components of this system

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

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.

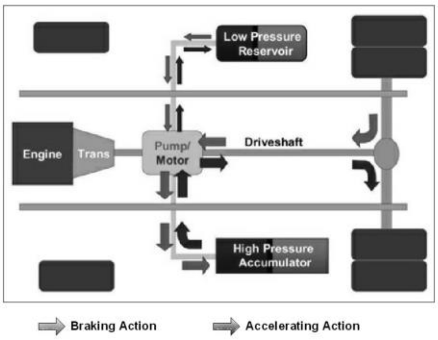

Fig. 3:Hydraulic Regenerative Brake (HRB)

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.

Usage of 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.

Regenerative Braking Using Nitilon Spring:

From fig it is clear that while breaking 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.

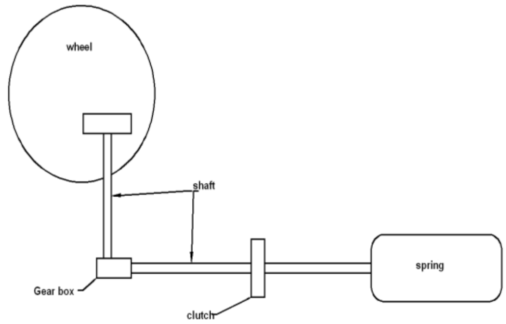

Fig 4: Regenerative braking using Nitilon Spring

III. BASIC ELEMENTS OF THE SYSTEM

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

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.

Batteries:

With this system as we know, the electric motor of a car becomes a generator when the brake pedal is

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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.

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.

Continuously Variable Transmission (CVT)

Fig 5: 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.

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.

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.

Super Capacitors:

Electric car can have different energy storage devices such as lead-acid, Ni-Cd, Ni-Metal Hydride. Li-ion and etc. Nowadays, research interest on connecting Li-ion batteries and super capacitors, as combination of two provide both high energy and power density. Super capacitors exhibits high power density which makes them suitable to provide/accept power at peak loads i.e. During transient state such as acceleration/ Braking simultaneously. While specific energy is provided by batteries to provide power in steady state, it is responsible for range of vehicle. Super capacitors have emerged as new technology in energy storage.

IV. CONTROL STRATEGY

Control strategy depends on size of super capacitor bank, larger the capacity of bank vehicle can accelerate/decelerate taking an almost average current, as super capacitor will provide all current above and below average current. Large number of super capacitor can't be employed as they are costly, so more complicated and intelligent control strategy need to be designed to use super capacitor efficiently.

Primary Control:

Primary control maintains adequate level of charge in super capacitor. This charge is known as reference charge and it is calculated through the speed of vehicle and state of charge of battery pack. Higher the state of charge of battery and vehicle speed lower the reference

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charge and vice-versa. Simultaneously VCAP is measured and actual charge is calculated. An error signal is generated between actual and reference charge and passed through proportional and integral(PI) control, it calculate reference current(IREF) necessary to maintain super capacitor bank adequate amount of charge. Load Current (ILOAD) is also an important reference, when this current exceeds maximum absolute value set on battery pack(IBATT), the reference current(IREF) is also modified.

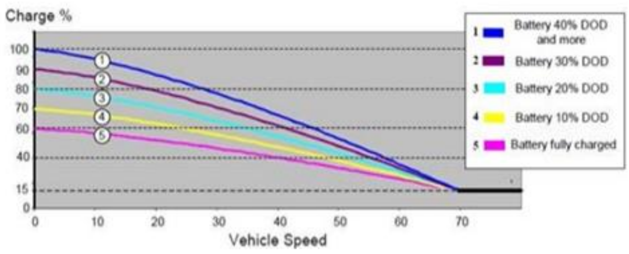

Fig 6: charge in capacitors at variable speed and SOC of battery

Secondary Control:

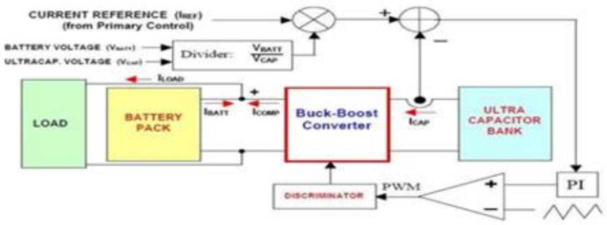

Fig 7: Block diagram of secondary control

The reference current from primary control finally goes to secondary control and decides the amount of compensating current (ICOMP) required to compensate charge of super capacitor. During acceleration ICOMP became positive (ICOMP taken from Super capacitor bank) while during regeneration ICOMP became negative (ICOMP goes into Super capacitors). Discriminator block will decide whether convertor works under Buck or Boost operation this is how adequate charge is maintained in super capacitor. But what happens when battery voltage (VBATT) is below or above rated voltage, IREF is modified and a similar action will be performed as in case of super capacitor. To take in account all these situationssome logic rules have been implemented and these logic rules are performed inside limiter block.

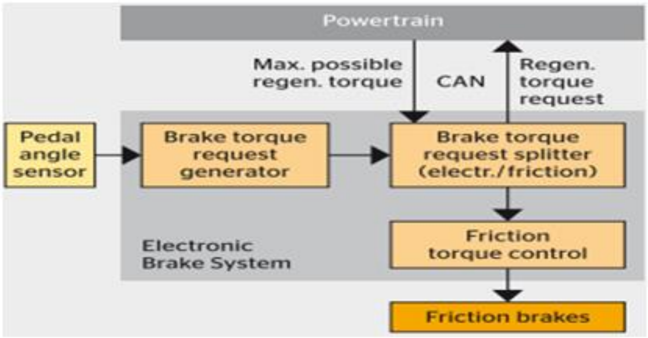

Fig 8: Brake torque blending overview

V. DESIGN REQUIREMENTS OF RBS:

- Store energy while braking

This is the basic function of any regenerative brake.

- Return energy to start up

Once the energy is stored in the device, it is necessary to have a simple way to release this energy back to the user in a positive way.

- Must fit to the vehicle

This is one of the most difficult constraints to achieve and most important because we have to with such confined spacing.

- Light weight
- Good stopping range

This component can be optimized to have the shortest stopping distance

- Good stopping force
- Inexpensive and affordable
- Safe to user and environmentally friendly

Safety is always a very important aspect whenever there is a consumer product.

- Reliable

Energy efficiency:

In June 2006, Tesla Motors reported the Roadster's battery-to-wheel efficiency as 110 W·h/km (17.7 kW·h/100 mi) on an unspecified driving cycle—either a constant 60 mph (97 km/h)) or SAE J1634 test—and stated a charging efficiency of 86% for an

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overall plug-to-wheel efficiency of 128 W·h/km (20.5 kW·h/100 mi).

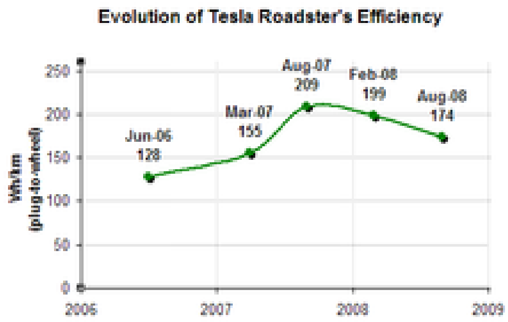

Fig 9: Tesla efficiency growth

Evolution of the Roadster's plug-to-wheel efficiency (smaller values indicate better efficiency) In March 2007, Tesla Motors reported the Roadster's efficiency on the EPA highway cycle as "135 mpg [U.S.] equivalent, per the conversion rate used by the EPA" or 133 W·h/km (21.5 kW·h/100 mi) battery-to-wheel and 155 W·h/km (24.9 kW·h/100 mi) plug-to-wheel. The official U.S. window sticker of the 2009 Tesla Roadster showed an EPA rated energy consumption of 32 kW-hrs/100 mi in city and 33 kW-hrs/100 mi on the highway, equivalent to 105 mpg city and 102 mpg highway. The EPA rating for on board energy efficiency for electric vehicles before 2010 was expressed as kilowatt-hour per 100 miles (kW-hrs/100 mi).Since November 2010, with the introduction of the Nissan Leaf and the Chevrolet Volt, EPA began using a new metric, miles per gallon gasoline equivalent (MPGe). The Roadster was never officially rated by the EPA in MPGe.In August 2007, Tesla Motors' dynamometer testing of a Validation Prototype on the EPA combined cycle yielded a range of 221 mi (356 km) using 149 W·h/km (23.9 kW·h/100 mi) battery-to-wheel and 209 Wh/km (33.6 kW·h/100 mi) plug-to-wheel.

Regenerative Braking Efficiency:

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. In a century that may see the end of the vast fossil fuel reserves that have provided us with energy for automotive and other technologies for many years, and in which fears about carbon emissions are coming to a peak, this added efficiency is becoming increasingly important. The added efficiency of regenerative braking also means less pain at the pump, since hybrids with electric motors and regenerative brakes can travel considerably farther on a gallon of gas, some achieving more than 50 miles per gallon at this point. And that's something that most drivers can really appreciate.

Advantages of Regenerative 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. Representing the significant cost saying to its owner, it

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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.

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.

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.

Limitations of Regenerative Braking Systems:

• The main limitation of regenerative brakes when compared with dynamic brakes is the need to closely match the electricity generated with the supply. With DC supplies this requires the voltage to be closely controlled and it is only with the development of power electronics that it has 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).

• Regenerative braking is necessarily limited when the batteries are fully charged. Because the additional charge from regenerative braking would cause the voltage of a full battery to raise above a safe level, our motor controller will limit regenerative braking torque in this case.

• Increases the total weight of vehicle by around 25-30 Kilograms

VI. 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

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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.

Future Scope:

- World's leading automakers like Ferrari, Renault, BMW, McLaren, Tesla are developing hybrid and also complete electric cars and are trying to add this Regenerative braking systems (RBS) to them
- The efficiency of IC engine vehicles is 20-25%. By using electric vehicles the efficiency increases by 50%. (i.e., 70-75%). Using RBS it contributes to the improvement of the overall efficiency of electric vehicles by providing braking feature and also saving most of the energy at the same time, which gets wasted. So by this system the efficiency can be increased approximately by 15% (i.e., 85-90%)
- Maximum efficiency from the automobiles which are to be introduced in near future is possible by this RBS.

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