Regenerative Brake: To Harness the Kinetic Energy of Braking

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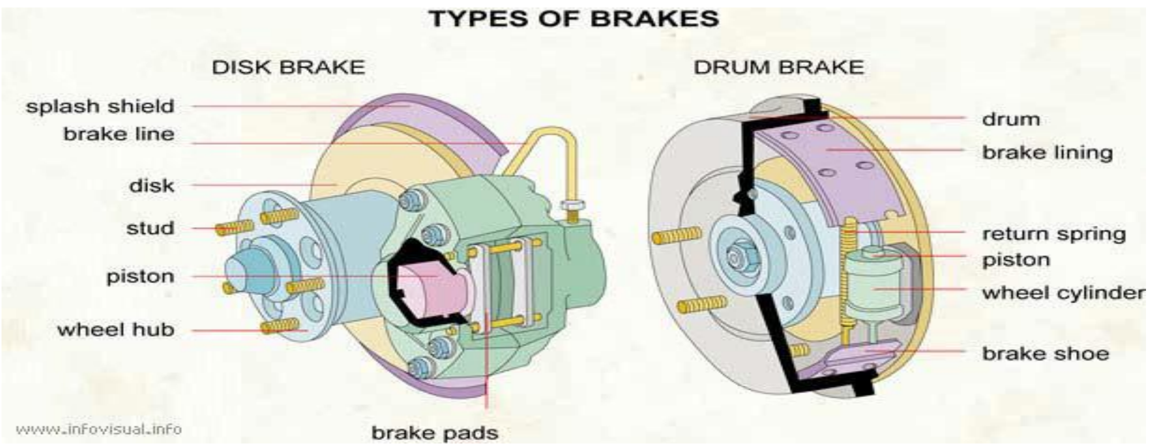
***Abstract*— Regenerative Braking Systems (RBS) provide an efficient method to assist railways and hybrid electric buses to achieve better fuel economy while lowering exhaust emissions. In this paper regenerative braking concepts have to be studied in order to find an optimal way to combine a regenerative braking with a conventional frictional braking system to achieve maximal energy recuperation .This paper describes the principle, design and working of regenerative braking systems. A typical regenerative braking pattern is investigated for evaluating the availability of braking energy recovery. The results indicates that in a vehicle with active regenerative braking control, a significant amount of braking energy can be recovered, and the brake system does not need much changing from the brake systems of conventional passenger cars.**

***Keywords*- Regenerative brake, Kinetic energy, Electric vehicle, Motor**

I. INTRODUCTION

When a conventional vehicle applies its brakes, kinetic energy is converted to heat as friction between the brake pads and wheels. This heat is carries away in the airstream and the energy is effectively wasted .The total amount of energy lost in this way depends on how often, how hard and for how long the brakes are applied. Regenerative braking refers to a process in which a portion of the kinetic energy of the vehicle is stored by a short term storage system. Energy normally dissipated in the brakes is directed by a power transmission system to the energy store during deceleration. That energy is held until required again by the vehicle, whereby it is converted back into kinetic energy and used to accelerate the vehicle. The magnitude of the portion available for energy storage varies according to the type of storage, drive train efficiency, and drive cycle and inertia weight. A City Centre driving involves many more braking events representing a much higher energy loss with greater potential savings. With buses, taxis, delivery vans and so on there is even more potential for economy. Since regenerative braking results in an increase in energy output for a given energy input to a vehicle, the efficiency is improved. The amount of work done by the engine of the vehicle is reduced, in turn reducing the amount of prime energy required to propel the vehicle. In order for a regenerative braking system to be cost effective the prime energy saved over a specified lifetime must offset the initial cost, size and weight penalties of the system. The energy storage unit must be compact, durable and capable of handling high power levels efficiently, and any auxiliary energy transfer or energy conversion equipment must be efficient, compact and of reasonable cost[1]. The possibility of recovering vehicle kinetic energy is one inherent advantage of electric and hybrid electric vehicles. When a vehicle drives in heavy traffic more than half of the total energy is dissipated in the brakes. Therefore, recovering braking energy is an effective approach for improving the driving range of EV (Electric Vehicle) and the energy efficiency of HEV (Hybrid Electric vehicle) [2]. Developments in Hybrid Electric and pure Electric Vehicles are intended to improve the operational efficiency of road vehicles. Regenerative braking, which has long been established in rail vehicles, is integral to efficiency improvement, with up to 30% of overall traction energy demand satisfied by energy saved during deceleration[3]. Regenerative braking allows electric vehicles to use the motor as a generator when the brakes are applied, to pump vehicle energy from the brakes into an energy storage device. Regenerative braking is an effective approach to extend the driving range of EV and can save from 8% to as much as 25% of the total energy used by the vehicle, depending on the driving cycle and how it was driven [4].Generally, the regenerative braking torque cannot be made large enough to provide all the required braking torque of the vehicle. In addition, the regenerative braking system may not be used under many conditions, such as with a high state of charge State of Charge (SOC) or a high temperature of the battery. In these cases, the conventional hydraulic braking system works to cover the required total braking torque. Thus, cooperation between the hydraulic braking system and the regenerative braking system is a main part of the design of the EV braking control strategy and is known as torque blending. In the present work the principle, design and working of regenerative braking systems is proposed and a typical regenerative braking pattern is investigated for evaluating the availability of braking energy recovery. The results indicates that in a vehicle with active regenerative braking control, a significant amount of braking energy can be recovered, and the brake system does not need much changing from the brake systems of conventional passenger cars.

II. CONVENTIONAL BRAKING SYSTEM



A brake is a device for slowing or stopping the motion of a machine or vehicle, or alternatively a device to restrain it from starting to move again. The kinetic energy lost by the moving part is usually translated to heat by friction. Alternatively, in **regenerative braking**, much of the energy is recovered and stored in a flywheel, capacitor or turned into alternating current by an alternator, then rectified and stored in a battery for later use. First regenerative brake was adopted in 1930's at the sections having continuous slope. 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. Understanding how regenerative braking works may require a brief look at the system it replaces. Conventional braking systems use friction to counteract the forward momentum of a moving car. As the brake pads rub against the wheels (or a disc connected to the axle), excessive heat energy is also created. This heat energy dissipates into the air, wasting up to 30% of the car's generated power. Over time, this cycle of friction and wasted heat energy reduces the car's fuel efficiency. More energy from the engine is required to replace the energy lost by braking.

III. NEEDS OF REGENERATIVE BRAKE

Braking always results in huge loss of energy, kinetic energy increases with the square of the velocity ($E = m \cdot v^2$ relationship). This means that if the speed of a vehicle doubles, it has four times as much energy. The brakes must therefore dissipate four times as much energy to stop it and consequently the braking distance is four times as long. Today, we are living in such a stage where everybody is thinking "how to save the energy?" which leads to better environment. As in today's world, where there are energy crises and there sources are depleting at a higher rate, there is a need of specific technology that recovers the energy, which gets usually wasted. So, in case of automobiles one of these useful technology is the regenerative braking system. Generally in automobiles whenever the brakes are applied the vehicle comes to a halt and the kinetic energy gets wasted due to friction in the form of kinetic energy. Using regenerative braking system in automobiles enables us to recover the kinetic energy of the vehicle to some extent that is lost during the braking process. In this paper the author discusses two methods of utilizing, the kinetic energy that is usually wasted by converting it into either electrical energy or into mechanical energy. Regenerative braking system can convert the kinetic energy into electrical energy with help of electric motor and it can also convert the kinetic energy into mechanical energy, which is supplied to the vehicle whenever it is needed, with the help of a flywheel [6]. In the years following the energy crisis numerous researchers have studied the feasibility and practicality of implementing hybrid power trains incorporating regenerative braking which have the potential to improve the fuel economy of vehicles operating under urban driving conditions [1]. The price increase of petroleum based fuel in the past few years has also given rise to various research and development efforts for energy conservation. However reduced fuel consumption and therefore operating cost and reduced gaseous emissions including primarily carbon dioxide (hence global warming) are the major driving forces behind commercial considerations of such systems [14,15,16].

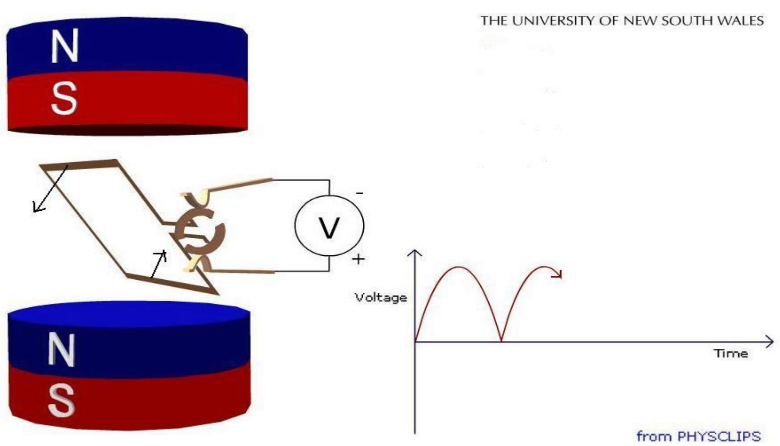
IV. BASIC IDEA BEHIND REGENERATIVE BRAKE

Consider a bicycle fitted with dynamo, when the dynamo is engaged with wheel it is harder to peddle .That's because, some peddle energy is stolen by the dynamo and turned in to electrical energy. Suppose a situation we are going at some speed and we suddenly stop peddling and at the same time turn on the dynamo it will bring us to stop position, because kinetic energy is stolen by the dynamo. Similarly in case of vehicle, when we engage the regenerative brake the braking energy will reduce the vehicle speed by converting some of its kinetic energy into some other kind of useful form of energy – electric current, compressed air [7].

V. THE MOTOR AS A BRAKE

Regenerative braking utilizes the fact that an electric motor can also act as a generator. The vehicle's electric traction motor is reconnected as a generator during braking and its output is connected to an electrical load. It is this load on the motor that provides the braking effect. 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. An early example of this system was the Energy Regeneration Brake, developed in 1967 for the Amitron. This was a completely battery powered urban concept car whose batteries were recharged by regenerative braking, thus increasing the range of the automobile.

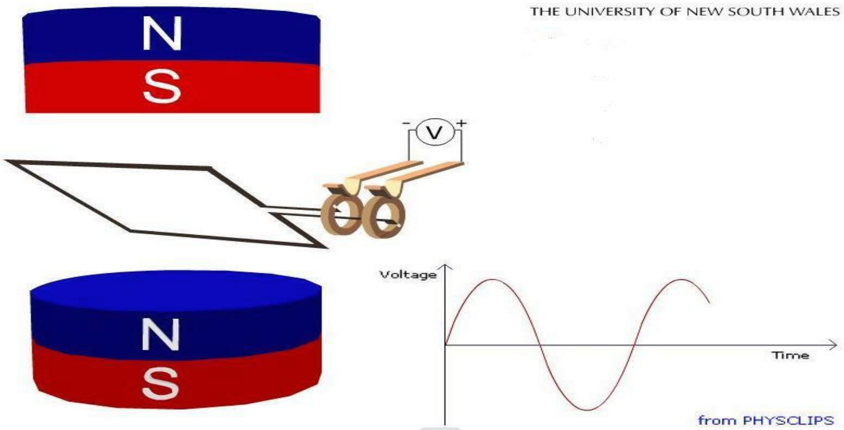
VI. PRINCIPLE OF WORKING



If you use mechanical energy to rotate the coil (N turns, area A) at uniform angular velocity ω in the magnetic field **B**, it will produce a sinusoidal emf in the coil. Let θ be the angle between **B** and the normal to the coil, so the magnetic flux φ is NAB.cos θ.
Faraday's law gives:

Emf = − dφ/dt = − (d/dt) (NBA cos θ)
= NBA sin θ (dθ/dt) = NBAω sin ωt.

If we want AC, we don't need recification, so we don't need split rings.The two brushes contact two continuous rings, so the two external terminals are always connected to the same ends of the coil. The result is the unrectified, sinusoidal emf given by: NBAω sin ωt.

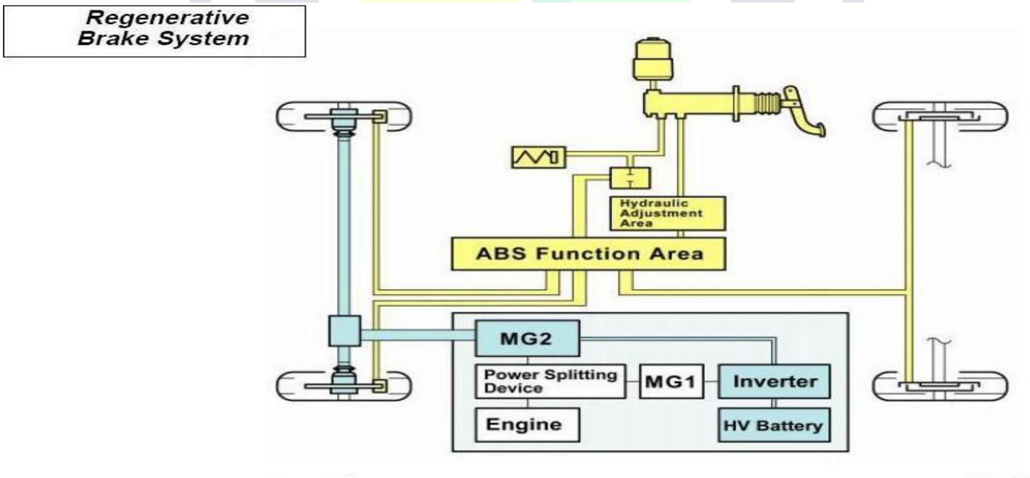


VII. ENERGY SAVING AFTER IMPLEMENTING REGENERATIVE BRAKE

KINETIC ENERGY =1/2 mv^2
Consider a 300kg vehicle moving at an initial speed of 72km/h (20m/s), on braking the vehicle comes to a speed of 32km/h (8.88m/s).
Initial K.E = ½*300*$(20)^2$ =60kJ
Final K.E = ½*300*$(8.88)^2$ =11.85kJ
Energy lost in braking = (60-11.85) kJ
If regenerative brake is used with at least braking efficiency 25% then also 12.03KJ (25%of 48.15kJ) energy is available at each braking instance which can be used for beneficial purpose.
This much energy is roughly enough to accelerate a car from 0 km/h to 32 km/h.

As, $V = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2*12.03*1000}{300}} = 8.95m/s(32km/h)$

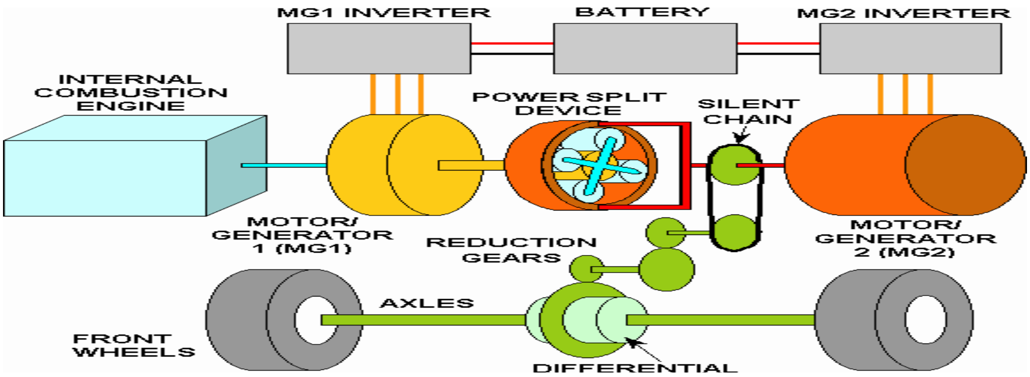
VIII. CONSTRUCTION OF REGEENERATIVE BRAKE



Source: - Toyota hybrid system

Regenerative braking takes energy normally wasted during braking and turns it into usable energy. It is not, however, a perpetual motion machine. Energy is still lost through friction with the road surface and other drains on the system. The energy collected during braking does not restore all the energy lost during driving. It does improve energy efficiency and assist the main alternator. Regenerative brake uses motor as a brake. The drive axle and MG2 are joined mechanically. When the drive wheels rotate MG2 it tends to resist the rotation of the wheels, providing both electrical energy and the brake force needed to slow the vehicle.

IX. ENLARGED VIEW OF REGENERATIVE ASSEMBLY

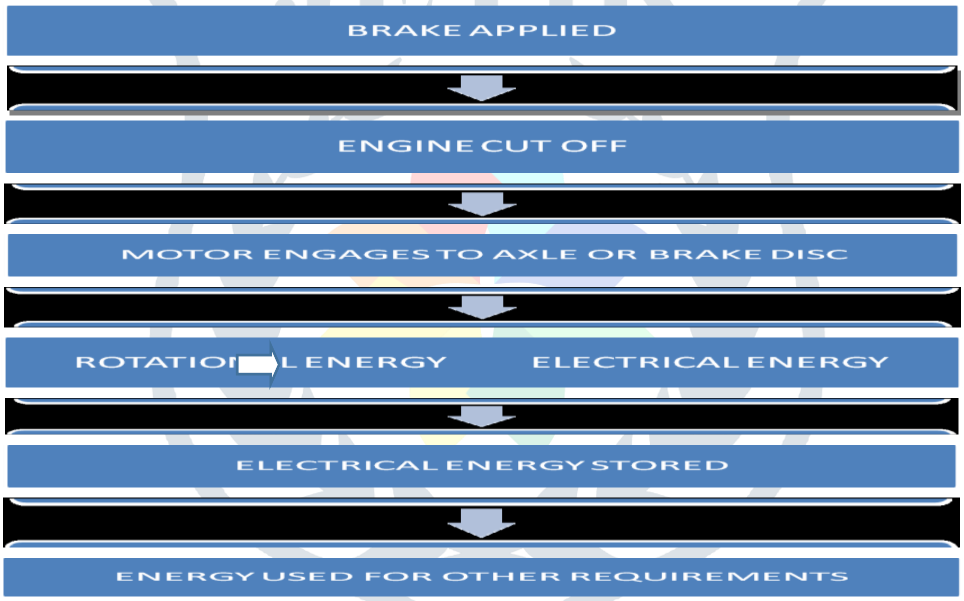


Source: - Toyota Prius hybrid system

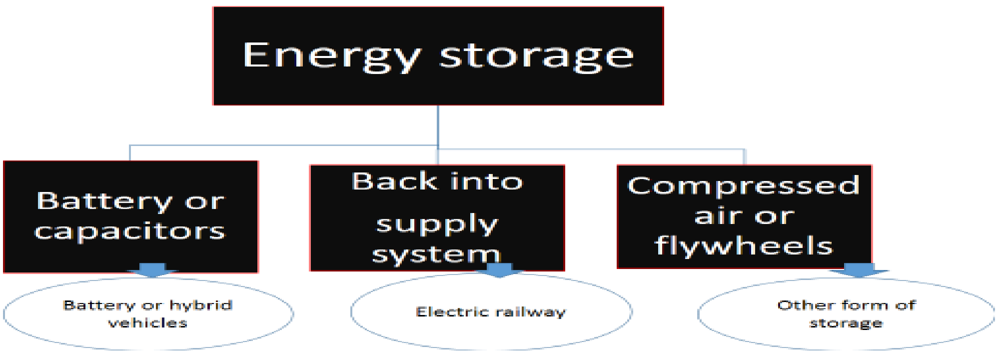
Regenerative brake consists of:-

1. A driving wheel linked with a rotary shaft
2. A motor
3. A battery charging circuit
4. A set of batteries or other storing device.

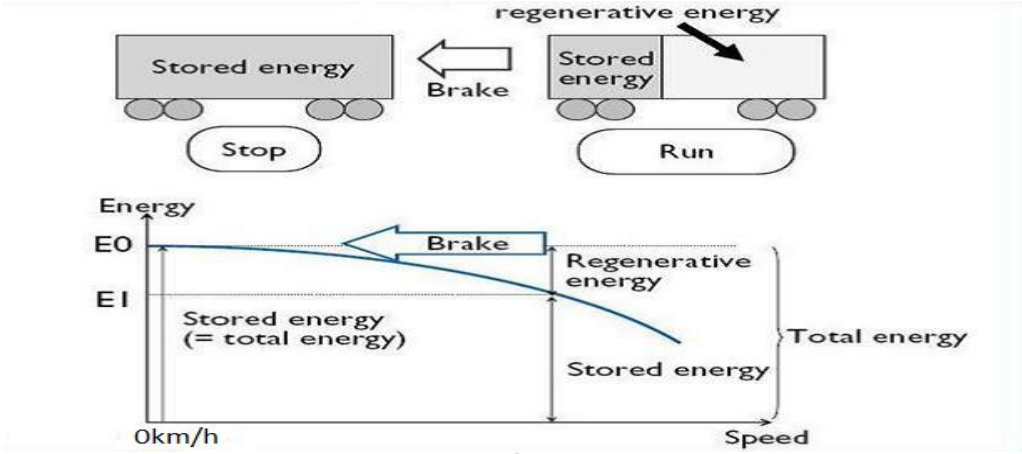
X. OPERATION CYCLE



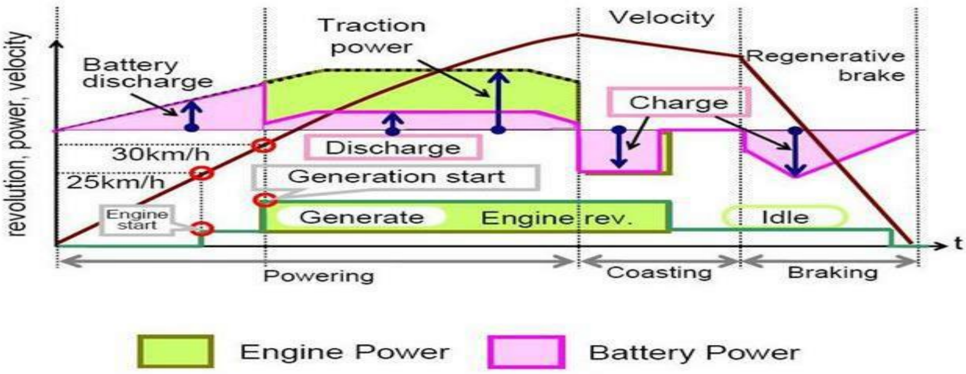
XI. ENERGY STORAGE SYSTEMS



XII. ENERGY STORING MECHANISM IN A VEHICLE



XIII. ELECTRIC RAILWAY VEHICLE OPERATION



During braking, the traction motor connections are altered to turn them into electrical generators. The motor fields are connected across the main traction generator (MG) and the motor armatures are connected across the load. The MG now excites the motor fields. The rolling locomotive or multiple unit wheels turn the motor armatures, and the motors act as generators, either sending the generated current through onboard resistors (dynamic braking) or back into the supply (regenerative braking) For a given direction of travel, current flow through the motor armatures during braking will be opposite to that during motoring. Therefore, the motor exerts torque in a direction that is opposite from the rolling direction. Braking effort is proportional to the product of the magnetic strength of the field windings, times that of the armature windings.

XIV. ADVANTAGE OF REGENERATIVE BRAKES

The following values are typical (referring to total energy demand) for different operation types	
Main lines:	15%
Regional lines:	35 %
Suburban lines:	45%
Freight lines:	20%

1. Exhaust emissions were reduced by about 35 per cent (Such emissions include nitrogen oxide, carbon monoxide, carbon dioxide, total hydrocarbons and particulates.)
2. Cost of engine maintenance was reduced by at least 50 per cent because there was less wear on the brakes and tires and less lubricating oil was needed.
3. Environment friendly.
4. Noise level was lower by 30 per cent.

XV. LIMITATION OF REGENERATIVE BRAKES

1. It cannot be used as an alternative of conventional braking.
2. The regenerative braking effect rapidly reduces at lower speeds, therefore the friction brake is still required in order to bring the train to a complete halt.
3. The friction brake is a necessary back-up in the event of failure of the regenerative brake.

XVI. CONCLUSION

1. Regenerative brake can save a good amount of energy efficiently in stop & go traffic condition which is more common in metropolitan traffic.
2. As fuel price is increasing day by day, in such situation use of regenerative brake encourages the development of electric vehicles because it works more efficiently in such vehicle.
3. Regenerative brake can be implemented in conjunction with antilock braking system.
4. 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.

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