A review of Regenerative Braking Systems

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Abstract : Nowadays maximum efficiency and minimum fuel consumption are the main criteria for research and development in the automotive field. With the world looking forward to electric and hybrid systems as options to the Internal combustion engines, regenerative braking is found the be a promising technology in the future vehicles. Regeneration can be achieved by a variety of ways like hydraulic, electric and flywheel technologies. Kinetic Energy Recovery Systems (KERS) have found a great variety of applications. The main principle is to recover some of the energy lost while braking. This paper aims to discuss the basic concepts of regenerative braking along with their advantages and disadvantages.

I. Introduction

Braking in vehicles in used to stop or slow the vehicles, and is achieved by the use of friction to counteract momentum .As the brake pads rub against the discs, heat is generated . This heat is dissipated into air , which amounts to about 30%[1] of the vehicles generated power. Constant usage leads to reduction in overall efficiency of the vehicle. Also the reduction in speed needs to be overcome by accelerating , which call for more input of energy. Hence a new method of braking called regenerative braking system is devised which recovers a part of energy while braking. This system is rapidly gaining acceptance in hybrid and electric vehicles.

II. Regenerative Braking systems:-

Regenerative braking systems try to make the use of energy which might have been wasted in form of heat. The first thermodynamic law states that energy is always conserved . This is a type of braking system that can recollect a part of the car's kinetic energy and convert it into electrical energy or mechanical energy. The energy captured by regenerative braking is stored in one of three devices: an electrochemical battery, a flywheel, in a regenerative fuel cell. The use of regenerative braking system not only increases the efficiency but also saves energy. This can also be used for special purposes such as acceleration boost as in F1 cars. The amount of work done by the engine of the vehicle is reduced, in turn reducing the amount of energy required to drive the vehicle. The regenerative braking system is mostly backed up by the conventional braking system, due to the fact that it does not achieve zero acceleration .Also, during hard braking situations energy released is more than what can be absorbed by the regenerative system, at those times conventional braking takes the lead.

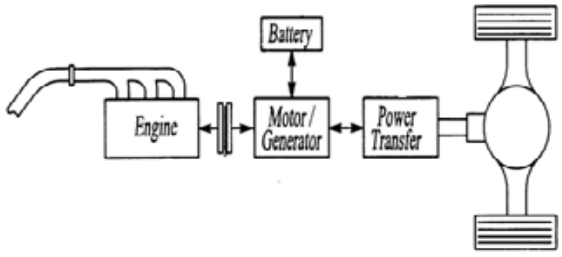

Figure 1: Simple Regenerative Braking system[1]

A) **Flywheel Energy Storage (FES) system:**

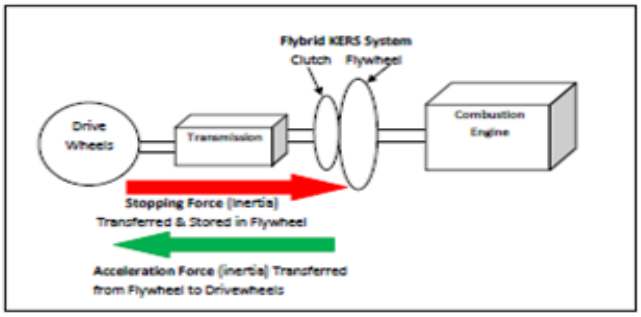

Figure 2: Schematic of flywheel based KERS

The kinetic energy of decelerating vehicle is used to accelerate a flywheel. The energy is hence stored in form of rotation of flywheel. The term "Flywheel" was first used around 1784 during the industrial revolution. At this time flywheels came to use in steam boats and trains, and were also used as energy accumulators in factories. While accelerating the flywheel is coupled to the transmission by using a, Continuously Variable Transmission(CVT) module. A continuously variable transmission is a device that changes the radius on which the chain rests ,so as to continuously change the gear ratio, allowing the rider to shift the transmission, form fast rotating crank to high rpm flywheel. The main limit for flywheel performance is the efficiency of the transmission connected to the flywheel. The flywheel can get up to speeds of 60,000 rpm.[3] For this reason the flywheel is stored in a vacuum sealed chamber and suspended with magnetic bearings. Flywheels are costly over batteries since flywheel technology in small road vehicles is not well developed, but there is a promising future in flywheel hybrid cars. The benefit of using flywheel technology is that more of the kinetic energy of the car can be directly captured , compared to batteries, because the flywheel can be engaged within short intervals of braking and acceleration.
Theoretical investigations of a this braking system show about 15% saving in fuel consumption.[6]

B) Hydraulic Storage System:-

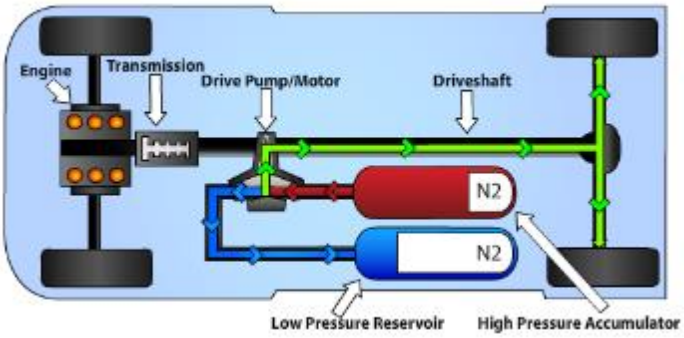

Figure 3 : A Hydraulic storage system

Regenerative braking in vehicles having hydro pneumatic accumulators along with variable displacement pumps has attracted considerable interest during the last 20–25 years. It can be used to provide high power for acceleration and can also recover power more efficiently during regenerative braking in comparison with electric counterparts . Fluid is stored in a low-pressure reservoir. A pump is used to move the fluid from reservoir to a high-pressure accumulator. The accumulator holds not only the fluid brought over by the pump, but also pressurized nitrogen gas. When the vehicle accelerates, the pressure is released from the accumulator which is used to spin the shaft and accelerate the vehicle.
These systems are of three types:-

- Purely Hydraulic System - The pure hydrostatic (integrated or series) system is based on purely hydrostatic transmission and requires a pump and pump motor. The function of the pump is dependent on whether the vehicle is being driven with positive torque or using regenerative braking.

- Hydraulic Power Assist(HPA)- The power assist (parallel) system requires only a single pump plus some type of transmission either a discrete ratio gearbox or **CVT.** If a gear box is used, the engine speed is not completely independent of vehicle speed This configuration is unique in that failure of the hydraulic system will not stop vehicle being operated.

- Power Split (hydro mechanical) system consists of two variable displacement hydrostatic units, a power dividing differential and an accumulator. This configuration offers the advantages of regenerative braking along with the possibility of running the engine at its highest efficiency much of time and at efficiencies equivalent to a conventional car the rest of the time. It is the most complex type in terms of design.[2]

C) Electrical Storage System:-

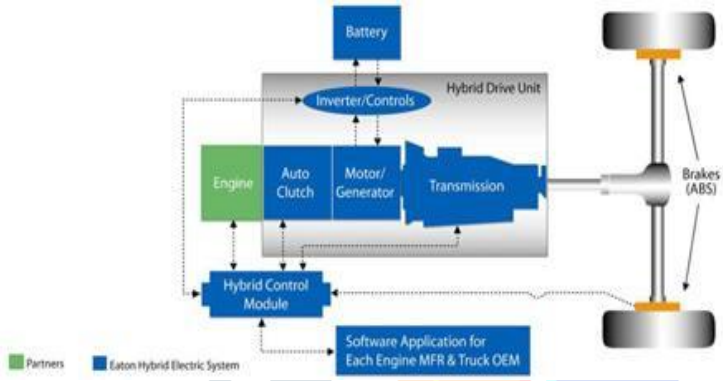

Figure 4: A general electric storage system

Electrically driven vehicles can give a saving of energy as they can convert KE to electrical energy for storage and re-use. The drive motor of an electric vehicle can be made to operate as a generator supplying a resistive load and braking torque to the wheels. This makes the concept of regenerative braking all the more important in such vehicles due to the fact that they carry limited electric energy on-board their energy storage systems.. In regenerative braking, the electric vehicle motor operates as a generator to charge the battery. Every kilowatt-hour of energy saved leads to increased mileage of the vehicle. The braking system can be controlled by using pulse with modulation signal from a microcontroller. A higher resistance would generate a PWM signal with a higher magnitude cycle and in turn, a harder braking intensity. Therefore, by varying the resistor value, the braking intensity can also be varied. The process is less efficient at low power because of the reserved mechanical losses, thus regeneration is not possible at low speeds and must be supplemented by mechanical brakes. Since a combination of electric motor/generator braking and mechanical friction braking is used to provide the required vehicle braking torque, electronic algorithms are devised which relate to the splitting of the braking command between the two braking mechanisms. These algorithms, known as braking strategies , are devised to reduce the overall energy consumption of the vehicle by utilizing the knowledge of the regenerative braking capability boundaries. The various strategies and their results have been discussed in [8].
The main advantage is that ,other than the weight of battery/storage unit, there is no significant increase in weight of the vehicle. The transmission system needs to be altered along with it the usage of CVT is preferred.[6]. Primary calculations based on gross weight of cars (BMW 316i, Tesla model S) have been discussed in [9].

III. A review on efficiency of Regenerative Braking:-

Energy efficiency of conventional vehicles is about 20%-25%, the rest of the energy is wasted mainly in form of heat. By using regenerative braking systems fuel consumption can be reduced upto 10 to 20 %, that is the efficiency can be increased

upto 45%. Using the hydraulic KERS 15% fuel economy has been proved.[5]The recovery system efficiency of 60% in MATLAB environment is also impressive.

IV. Advantages of regenerative braking systems:-

- Energy efficient
- Emission reduction
- Improved performance & range (in case of Electric vehicles)[2]
- Reduction in engine wear (due to an assistance from hybrid drivetrain)
- Smaller accessories (downsized fuel tank, eliminated electric starter)[2]

V. Disadvantages of regenerative braking systems:-

- Added weight (battery, powertrain)
- Increased complexity (hybrid drivetrain)
- Cost (can be reduced by mass production)
- Added maintenance

VI. Future Scopes:-

With further improvements in technology and manufacturing techniques, the modern advanced flywheels, there would be no large pieces, and would be contained in a housing which will prevent injury of anyone nearby. With better capacitors and batteries the speed of charging of electric vehicles can be considerably increased.

The hydraulic system needs to be successfully tested and implemented in smaller vehicles.

Cars such as Tesla model 3 (range 215 miles predicted),Chevrolet spark EV (range 82 miles) are a proof that Electric vehicles are becoming more and more common.

VII. Conclusion:-

The regenerative braking systems are a promising hope for increased fuel economy and range for passenger vehicles. With further study and improvements they can cut down the fuel crisis. The hybrid hydraulic technology can be more useful for heavy vehicles and off- road vehicles. The Hydraulic Launch Assist (HLA) systems are being incorporated in trucks by companies like EATON hybrid systems.

Regenerative braking systems applied to the mass transportation sector like railways can save quite a considerable amount of electricity. With more advancement in this direction the principle of regeneration can be applied to industrial machinery also. Along with the hunt for an alternative energy sources this principle can help to control the fuel crisis.

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