A REVIEW ARTICLE ON REGENERATIVE BRAKING SYSTEM

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Abstract: ***In this 21st century, it is worth to saying the need for a vehicle, from four-wheelers to two-wheelers the demand of vehicle in the automobile sector is increasing day by day. With the rapid demand for vehicles, it is needless to say the raising of loss of energy in different aspects. In this review article, recovery of the loss of energy when we apply brakes on the wheels will be discussed. When a usual common vehicle applies its brakes, kinetic energy is changed to heat as friction between the brake pads and wheels. This heat is transferred to the system 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. The regenerative implies recovering energy and generating that for a new purpose. In a regenerative braking system, the heat energy which is produced during the application of the brake can be utilized for other purposes say to light up the light or charging up the battery etc. The use of regenerative braking system increases the work output for the same input resulting in better efficiency of the vehicle. This article was carried on to provide comprehensive information about regenerative braking systems. These systems provide economic benefits via fuel savings and prevention of material loss. Their use also contributes to a clean environment and renewable energy sources, which are among the most important issues on the global agenda. More comprehensive studies should be accomplished in this area.***

Key words: ***Regenerative brake, Hybrid Vehicle, Environment friendly, loss of heat dissipation***

I. INTRODUCTION

The rapid growth of population in the world raises the number of vehicles which is now a serious concern for the environment, human health as the pollution emitted by the vehicles polluted the air, causes global warming and depletion of ozone layer. The fast uses of petrol, diesel, coal also reduces the layer of natural fuel. After facing so many problems, some countries of the world have forced to implement some environmentally friendly measure, along with saving the energy throughout the world to a maximum level with the available resources in the era of energy crisis. Regenerative braking system amongst the one of the applications.

Regenerative braking is a type of braking system in which a portion of the kinetic energy of the vehicle is stored by a short-term storage system. During brake application in a running vehicle heat energy is produced due to the friction between the wheel and brake pad. That energy generally dissipates and it must be stored to minimize the loss of heat and it is then to be used in the other applications. In hybrid and electric cars regenerative braking system has an enormous application as both the cars uses electric engine to energize the car and the application of regenerative braking system makes it very efficient. The transmission system of the cars is set up in such a manner that once the driver applies brake the electric motor reverses itself and applies a resistance to the wheels rather than power. The resistance applied to the wheels is then put through the electric motor where it is used to recharge the battery. In recent years, the popularity of electric vehicles and hybrid electric vehicles has become so high as it does not require any fuel and save energy. Energy normally lost in the brakes which is directed by a power transmission system to the energy store during retardation. That energy is held until further requirement by the vehicle, whereby it is transformed into

The magnitude of the portion available for energy storage varies according to the type of storage, drive train efficiency, drive cycle and inertia weight.

There are seven different methods of conversion the energy in regenerative braking system which includes spring, flywheel, electromagnetic and hydraulic. In recent technologies electromagnetic-flywheel hybrid is emerging well. Each type of Regenerative Braking System has different energy conversion or storage method, giving varying efficiency and applications for each type.

Some important advantages of Regenerative Braking Systems can be summarised as:

- Improvement in fuel economy.
- Reduction in emission.
- Improvement in performance.
- Reduction in engine wear.
- Reduction in brake wear.
- Small accessories required.
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Limitations of Regenerative Braking Systems are:

The main limiting factor of regenerative brake in comparison with dynamic brake is that, it needs to match the electricity generated with the supply. With DC supply it requires voltage which is controlled closely and this is only possible by the development of the power electronics which closely matches the frequency of AC supplies.

When the batteries are fully charged, additional charge from the regenerative brake can cause the rise of the voltage above safe level which in turn limit the regenerative braking torque.

Cikanek & Bailey [1] discussed in their article about regenerative braking system (RBS) for a parallel hybrid electric vehicle which performs generative energy recovery based on the vehicle attributes which in turn provides improved performance and efficiency. Their RBS algorithm was modelled using analogue MATRIX algorithm and then developing the code using MATRIX Autocode. Bobba & Rajgopal [2] deals in their article about the design and modelling aspects of hybrid energy storage system (HESS) used in Electric vehicles. A simple power sharing algorithm based on heuristic approach is presented to ensure the different modes of operation of electric vehicles. This paper also describes different types of converters used in HESS for electric vehicle application along with its suitability to the light electric vehicles. Zhang, J., Lu, X., Xue, J., & Li, B [3] invented different methods of RBS system one of which is in series regenerative braking system and two are in parallel regenerative system. A Hardwire-in-the-loop (HIL) experimental setup is used for testing upon which series RBS system provides the best combination of energy recovery with acceptable drivability, safety and stability. Malode, S. K., & Adware, R. H. [4] proposed an easy and useful method of regenerative braking in electric vehicles (EVs). The loss of kinetic energy during braking can be converted back into electrical energy and stored in the battery or ultracapacitor. If this energy is properly managed, it can be carefully controlled without causing any problems for the motor, driver, or battery. Amrit Anand Mahapatra, S. Gopalkrishna [5] proposed a method for regenerative braking for the improvement of the energy management in the traction system through regeneration in which induction machine is operated with negative slip to obtain braking torque.

Guo J., Wang J., Cao B. [6] established a mathematical model for energy generation in electric vehicle to analyze the main properties which have the influence on brake energy regeneration. After analyzing the charge and discharge characteristic of battery and motor a simple regenerative braking strategy was proposed. The strategy takes braking torque required, motor available braking torque and the braking torque limit. Simulation results depicts higher energy regeneration compared to a parallel strategy. Nanda Kumar, C., & Subramanian, S. C. [7] approached for a brake force sharing (BFS) strategy between regenerative brake and friction brake. The vehicle model and BFS strategy were developed and IPG car maker software was used to evaluate the effectiveness the strategy. Further a closed loop structure was developed for implementing the strategy in electric and hybrid vehicle. Yang, Y., Luo, C., & Li, P. [8] developed two control strategies which are based on two separate rules, the maximum energy recovery rate strategy adheres to the rule of the maximization of the braking energy recovery rate, while the minimum current impact strategy adheres to the rule of the minimization of the charge current to the battery.

1.1 Conversion of Kinetic Energy to Electrical Energy:

In regenerative braking system basically, an electric motor is used which is an important component acts as an electric generator.

The working principle of a regenerative braking system based on the working principle of an electric motor. When an external force applied on an electric motor to activate it, it behaves like an electric generator and generates electricity. It means when an electric motor rotates in a particular direction the electrical energy is converted to mechanical energy which in turn accelerate the vehicle and whenever the electric motor runs in opposite direction it acts as a generator and converts the mechanical energy to electric energy which is used to recharging the battery, lighting up the lights etc [9].

II. WORKING PRINCIPLE OF REGENERATIVE BRAKING SYSTEM

Regenerative braking is a type of braking method in which charging is done to the battery by transforming the mechanical energy of the motor and kinetic energy into electrical energy. When braking force is applied to the brake pedal, the wheels slows down and the motor runs in the opposite direction. When the operation is carried on in the reverse direction, the engine acts as a generator and converts its torque energy into electrical energy. That's how the fuel consumption and emissions are minimized. In high-speed vehicles, the braking force is minimum, and therefore does not affect the traffic flow [10]. The new electric-hydraulic powertrain is a parallel hybrid system which consist of traction motor, battery, hydraulic pump / motor, hydraulic accumulator, reservoir, and a set of hydraulic valves. The hydraulic circuit consist of the drive circuit and the drain circuit. The drive circuit has the components like a cartridge valve, a one-way valve, and a two-position four-way valve.

When the brake is applied on the wheels, the valve is shifted to the left which forces the oil from the reservoir to flow towards the accumulator using pump. The pump then uses the kinetic energy of the vehicle to pressurize the oil in the reservoir to flow into the accumulator. The energy is stored in the accumulator and the vehicle slows down. The hydraulic system works in the regenerative braking mode [8].

2.1 Series Regenerative Braking System:

The vehicle's power train consists of an auxiliary power unit (APU), which includes an internal combustion engine connected to a generator and rectifier which can start the electric motor or recharge the batteries as per the directions given by the vehicle control unit (VCU). The electric motor basically controlled by the motor control unit which act as a drive motor or a generator. During regenerative braking, while the motor is operating as a generator, the battery can start the motor or absorb current from the APU and the electric motor. The structure of the RBS series consists of the RBS, the ABS and two duty valves which are used for adjusting the friction braking force. The working valves are installed on the front and rear brake lines. The elements which are used in the ABS can be used for this purpose and have a quick response time. The different states of the two valves determine the air pressure in the brake chambers. The mechanical braking force is controlled by the control unit under the directions of RBS control system by sending pulse width modulation (PWM) signals to the valve to control the pressure. When the electronic control unit (ECU) detects a lock on one of the rear wheels, the ABS controller gives a signal which in turn the vibrate the brake activate the modulator valve. As the RGS is mounted on the rear axle, the same signal can be used to control the regenerative braking force and to increase vehicle stability by minimizing wheel lock during hard braking operations.

2.2 Parallel Regenerative Braking System:

In parallel regenerative braking system both the electric motor and the mechanical braking system always work together in parallel to slow down the motion of the vehicle [11]. Regeneration of energy during the application of brake is important for a parallel HEV as because it enables the vehicle to reduce the consumption of fuel which in-turn improve the fuel economy of the vehicle and extend its driving range. To increase this energy during braking, the electric motor applies a negative torque to the wheels which convert some of the vehicle's kinetic energy into electrical energy to recharge the battery [12]. Since the mechanical braking process cannot be controlled independently of the brake pedal force, some of the kinetic energy of the vehicle is converted into heat energy and not in electrical energy. The hydraulic pressure of the master cylinder, which is a function of vehicle deceleration, determines the amount of regenerative braking power generated by the electric motor.

In order to maintain brake balance, the regenerative braking force is intended to be zero for high-speed deceleration since it depends on the motor speed and nearly no kinetic energy can be recovered at low motor speeds. Hydraulic pressure is detected by a pressure sensor, signaling that the master cylinder has to be slowed down. To operate the electric motor and provide the necessary braking torque, the pressure signal is controlled and supplied to the electric motor controller. The parallel regenerative braking technology is also easy to use and inexpensive. With this approach, the mechanical braking system just has to be slightly modified in order to include the electric motor into the system. Additionally, having a mechanical backup brake system is advantageous in situations where the primary braking system repeatedly fails [13].

III. FUTURE SCOPE

To create a better regenerative braking system that absorbs more energy and stops quicker, additional study is needed. Regenerative braking systems will become more and more popular as designers and engineers continue to refine them. By recapturing energy that would have been wasted during braking these technologies may help all moving vehicles by controlling the fuel consumption and increasing the efficiency. New types of motor, more powerful batteries which have efficient charging and discharging capabilities can be incorporated with regenerative braking system in the future prospect. New drive trains design with regenerative braking is also in vision of design engineers.

It is worth to say that so many problems may arise during in the application of new technologies in the future but the perfect technology should have more potential to make better efficiency for the vehicle than the regenerative braking system.

IV. CONCLUSION

The information of different methods of working principle of regenerative braking system along with its properties has been presented in this article. To recover the energy efficiently and to reducing the fuel and operating cost and to minimize the pollution many automation, electromechanical, and constructive studies have been carried out in this field. It has now become one of the important system for different aspects like safety, comfort and economic as it is continuously improving its technologies in different ways. Now it is only limited to electrical vehicles, can be used in conventional vehicles and resulting widely uses of regenerative braking system reduction of mechanical losses and saves energy by converting into electrical energy. As a consequence, these systems have a strong emphasis on energy recovery, minimizing energy usage, decreasing expenses, and providing clean air. For this reason, more thorough study on regenerative braking systems should be conducted and its findings conveyed to

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