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Regenerative Braking System: Comparative Study for Effective Use

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Abstract - *Conservation of natural resources has become a necessity in today's world, especially in the new technology as world is heading towards the brink of energy crisis. In automobile, a lot of energy is lost due to braking in forms of heat due to friction between brake pad and the disc. Regenerative braking refers to a process in which portion of the kinetic energy of vehicle is stored by short-term storage system. Regenerative braking system has different approaches to store and reuse the lost energy. This paper mainly highlights the different ways of recovering in electric vehicle or hybrid vehicle as well as normal vehicles. In addition, paper gives optimal way to combine a regenerative braking with a conventional frictional braking system to achieve maximal energy recuperation. This paper describes the principle and working along with the future scope of regenerative braking system.*

***Key Words*: Regenerative Braking system (RBS), Hybrid Electric Vehicle, Kinetic Energy Recovery system, Hydraulics**

1. INTRODUCTION

Regenerative braking refers to a process in which a portion of kinetic energy of a vehicle is store by short-term storage system. Energy normally dissipated in brakes is directed by a power transmission system to 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. Regenerative braking is an excellent way for vehicles to expand their driving capabilities. The regenerative braking plays a vital part to maintain the vehicle's strength and getting better energy. Traditional braking methodology causes a lot of wastage of energy since it produces unwanted heat during braking which is wasted in atmosphere without being recovered. Thus, the creation of regenerative braking has risen above these disadvantages in addition it helps in save energy and provide higher efficiency of vehicle.

1.1 Types of Regenerative Braking System

Using motor:

The most common form of regenerative brake involves using an electric motor as an electric generator. The working of regenerative braking system depends upon working principle of an electric motor, which is important component of the system. Electric motor gets activated when some electric current is passed through it. However, when some external force is applied to activate the motor (during braking when we apply force to pedal of brakes), then it behaves as a generator and generates electricity [1]. This means that whenever motor runs in one direction, the electric energy gets converted into mechanical energy, which is then used to accelerated the vehicle. Whenever the motor runs in opposite direction, it performs function of generator, which then converts mechanical energy into electrical energy, which makes it possible to utilize the rotational force of driving axle to turn the electric motors. Which results in regenerating electric energy for storage in battery and simultaneously reducing speed of car with regenerative resistance of electric motors. This electricity is then used for recharging the battery.

Flywheel Regenerative Braking System:

A flywheel is a component, which is used to store mechanical energy and then release the stored energy when needed for acceleration. Flywheel is a heavy high-speed rotating device that builds up kinetic energy as it spins. The amount of energy stored depends upon how heavier it is and how fast it rotates. Heavier weight and faster rotation results in higher energy storage. Hence the mechanical hybrid utilizes a rotating mass (or flywheel) as the energy storage device and a variable drive transmission to control and transfer the energy to and from the driveline. The transfer of vehicle kinetic energy to flywheel kinetic energy can be seen as a momentum exchange. Energy is drawn from the vehicle and supplied to the flywheel. In doing this, the speed of the vehicle reduces, (effectively this is braking), while the speed of the flywheel increases [2]. At the start of braking, the vehicle has a high speed and the flywheel a low speed, giving a certain gear ratio between them. At the end of braking, the vehicle has a low speed, and the flywheel a high speed, so the ratio of speeds has changed. Examination of the energy transfer shows that the ratio between vehicle speed and flywheel speed necessarily changes continuously during the energy transfer event.

Energy stored by flywheel is given by:

$E= \frac{1}{2} J\omega$

In addition, moment of inertia is given by:

$J= \frac{1}{2} mr^2$

Hydraulic Assisted Regenerative Braking System:

Hydraulic hybrid vehicle systems consist of four main components: the working fluid, reservoir, pump/motor (in parallel hybrid system) or in-wheel motors and pumps (in series hybrid system), and accumulator. In some systems, a hydraulic transformer is also installed for converting output flow at any pressure with a very low power loss[3]. In hydraulic hybrid system, the pump/motor extracts the kinetic energy during braking to pump the working fluid from the reservoir to the accumulator. Working fluid is thus pressurized. When the vehicle accelerates, this pressurized working fluid provides energy to the pump/motor to power the vehicle.

Regenerative braking in vehicles using a variable displacement hydraulic pump/motor together with a hydro-pneumatic accumulator has attracted considerable interest during the last 20–25 years. Such a system is particularly suitable for application in city buses. Despite the significant gains in the efficient use of energy that can be brought about by hydro pneumatic regenerative braking, its use has not attained great popularity. The added cost, which may represent 10–15% of the total for the vehicle, is undoubtedly a deterrent [3].

2. COMPARATIVE STUDY OF REGENERATIVE BRAKING

A comparative study of the regenerative braking system is done based on:

2.1 Voltage Stability.

2.2 Operating Temperature.

2.3 Efficiency.

2.4 Fuel Consumption.

2.5 Cost

2.1 Voltage Stability

There is always scope for improvement especially in terms of technology. The analysis was done based on the different types of storage system currently in use. It is also an overview of possible alternatives to the commonly used storage devices. It also highlights the drawback of a few RBS. Instability in voltage can lead to quick wear and tear of the energy storage device. In chart below there is comparison with other storage systems, flywheels offer maximum steady voltage and power level, which is independent of load, temperature and state of charge. Second being Lithium ion (Li-ion) battery followed by Nickle metal hydride NiMH and Lead-acid batteries. Super capacitors/ ultra-capacitors being the lowest with 30% stability. Reason being that super capacitors have self-discharge properties. Recent research suggests that this issue might be surmounted.

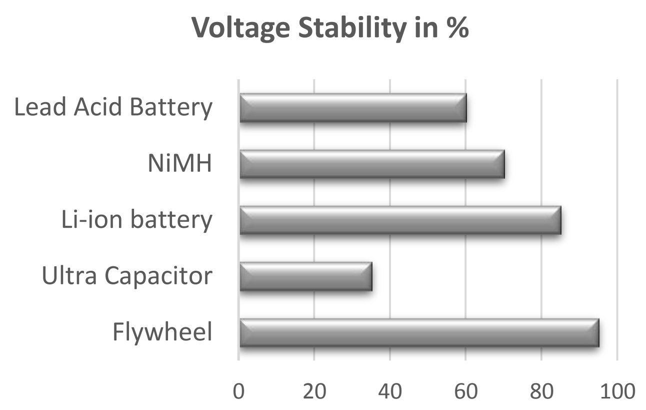

Fig -1: Voltage Stability for Different RBS

2.2 Operating Temperature

The charge and discharge of electrons cause temperatures to vary in storage devices. There are limitations to the temperature range that these devices can withstand. Fig 2 shows the extensive operating temperature range of these storage technologies. Flywheels again have the biggest temperature withstand range going from -40°C to 150°C as compared to the Lead Acid batteries which have the least range (-15°C to 50°C). Super-capacitors are the second best at withstanding a large temperature range with a minimum (similar to that of a flywheel) of 40°C and maximum of 70°C could replace the flywheel.

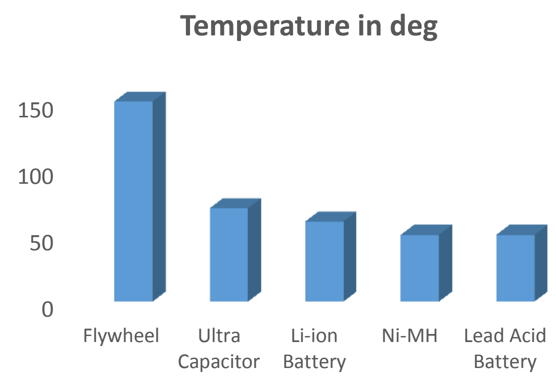

Fig -2: Operating Temperature for Different RBS

2.3 Efficiency

Efficiency in storage technologies can be defined as the amount of energy stored by the system to the amount of energy given out or utilized for other use. Fig. 3 shows that super capacitors have maximum efficiency with hydraulic storage devices not being too far from it which is followed by the presently in use mechanical RBS (i.e. flywheel). Batteries have the least efficiency because their discharge rate is faster as compared to the rate at which they charge. Even though super-capacitors have high efficiency, they cannot be used in RBS yet because at constant speed, super-capacitors cannot capture the kinetic energy lost while braking.

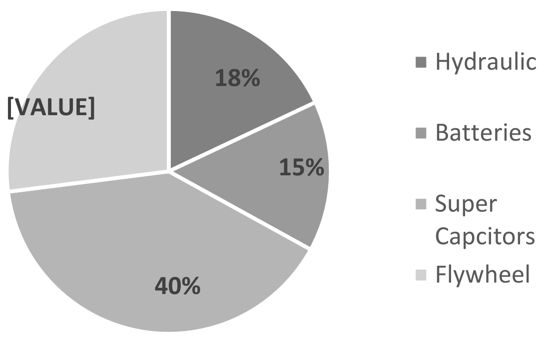

Fig -3: Efficiency for Different RBS

2.4 Fuel Consumption

Fuel consumption is the main aspect targeted by hybrid cars. This is to conserve and protect the non-renewable and natural resources. It is seen (from Fig 4) that 40% of fuel consumption reduction takes place if super-capacitors are prioritized as storage device. Second being flywheel with 27% followed by hydraulic energy system and batteries with 18% and 15% fuel consumption reduction respectively [3]. Batteries contribute least because they have short life and less conversion capacity as compared to other storage devices since their maximum and minimum temperature range is very small.

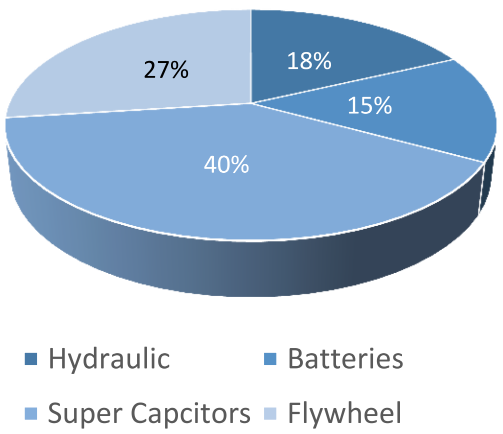

Fig -4: Fuel Consumption for Different RBS

2.5 Cost

Cost is the main drawback of every Hybrid vehicle. Causes of high cost are the materials used in making these vehicles and their storage technologies. Fig 5 shows that flywheel system is the cheapest after batteries with 15% and 6%. However, flywheels are currently use because of the efficiency they give in this low cost. Batteries cannot store enough energy and hence charge and discharge quickly. Hydraulic systems are the most expensive of them all followed by super-capacitors with 47% and 32% respectively.

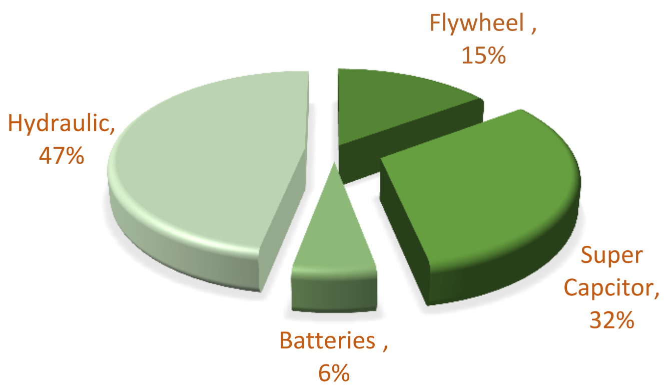

Fig -5: Capital Cost for Different RBS

3. FUTURE SCOPE

Regenerative braking systems requires further research to develop a better system that captures more energy and stop faster. As the time passes, designers and engineers will find perfect regenerative braking systems by capturing energy that would have been lost during braking process and thereby reducing fuel consumption and increased efficiency. Future technologies in regenerative brakes will include new types of motors which will be more efficient as generators, more powerful battery which can bear more frequent charging and discharging, new drive train designs which will be built with regenerative braking in mind, and electric systems which will be less prone to energy losses [4].

To be successful a regenerative braking system should ideally have the following properties:

- Efficient energy conversion
- An energy store with a high capacity per unit weight and volume
- A high power rating so large amounts of energy can flow in a short space of time
- Not require over complicated control systems to link it with the vehicle transmission
- Smooth delivery of power from the regenerative system

- Absorb and store braking energy in direct proportion to braking, with the least delay and loss over a wide range of road speeds and wheel torques.

Of course, problems are expected as any new technology is perfected, but few future technologies have more potential for improving vehicle efficiency than does regenerative braking.

As we know, our future vehicles will be having electric and hybrid vehicles, RBS is going to be next revolution in braking system.

4. CONCLUSIONS

Regenerative braking can save significant amount of lost energy as well as can sustain than conventional braking system. A thorough practical analysis and comparative method based on favorable characteristics for developing the system for commercial vehicles can save a good amount of energy efficiently in stop and go traffic condition, which is more common in metropolitan traffic. Besides, it has a wide scope of development in future that could lead to a huge savings of energy for the world.

To sum up this, we have gone through a sophisticated concept, which is a small, yet very important step towards our eventual independence from fossil fuels and will surely be much develop in coming days. Also, it would be a great showcase of technology which could have a major impact on the automobile industry in years to come. In the future, the technology could also be used on buses, trains, and wind power generation.

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