A Review on Regenerative Braking System

S. Jeeva Bharathi, R. Sri Hari Prasath, K. Sriram and A. Shankar

Abstract--- *In this review paper we present, Electric vehicles will be a necessary need for our use very soon. Today, in existing conventional braking technologies consumes a lot of energy during braking and as per the laws of physics (The energy can be neither created nor destroyed), while braking the heat energy converted for kinetic energy is dissipated into atmosphere. Therefore, regenerative braking is the most important method of conservation of energy. It increases the efficiency of electric vehicles by reducing waste of energy. In regenerative braking mode, the kinetic energy of the wheels is converted into electricity and stored in the battery or capacitor. Some existing systems are able to capture and store as much as 70% of energy. This method has been improved using flywheels, DC-DC converters, and super capacitors.*

Keywords--- *Regenerative Braking, Energy Recovery for Brake, Electric Motor, Generator, Batteries.*

I. INTRODUCTION

In the course of the depletion of natural fuel resources, the growth of their prices and the increase of environmental pollution, efforts have been made by researchers on electric/ hybrid vehicles to increase its battery capacity and it’s charging time to increase the usage of them. Regenerative braking systems (RBSs) are a type of kinetic energy recovery system that transfers the kinetic energy of an object in motion into potential or stored energy to slow the vehicle down, and as a result increases fuel efficiency. These systems are also called kinetic energy recovery systems. There are multiple methods of energy conversion in RBSs including spring, flywheel, electromagnetic and hydraulic. More recently, an electromagnetic-flywheel hybrid RBS has emerged as well. Each type of RBS utilizes a different energy conversion or storage method, giving varying efficiency and applications for each type.

RBSs are used in almost every electric vehicles and hybrid electric vehicles. In addition, public transportation such as buses and bullet trains make use of RBSs to decrease the environmental impacts of the transportation fleet and save money

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.

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A lorry on the highway could travel 100 miles between stops. This represents little saving even if the efficiency of the system is 100%. City Centre Driving involves many more braking events representing a much higher energy loss with greater Potential savings. 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.

II. LITERATURE SURVEY

Regenerative Braking System

Deepak Vishwakarma & Sayujya Chaurasia, Imperial International Journal of Eco-friendly Technologies, pp.27-30, Volume. - 1, Issue-1(2016), Regenerative Braking System recovers kinetic energy as much as possible that is lost during the process of braking. It stores that energy and releases it under acceleration. This paper highlights the two different methods of recovering energy that generally gets wasted, by converting it into either electrical or mechanical energy..

III. REGENERATIVE BRAKING SYSTEM (RBS) (FUTURE OF BRAKING)

Pulkit Gupta, Anchal Kumar, Sandeepan Deb& Shayan, International Journal of Mechanical and Production Engineering, ISSN: 2320-2092, Volume- 2, Issue- 5, May-2014, pg.75-78, The use of regenerative braking system in automobiles provides us the means to balance the kinetic energy of the vehicle to some extent which is lost during the process of braking. The authors of the paper have discussed and presented two methods of using the kinetic energy which generally gets wasted by converting it into either mechanical energy or into electrical energy. Flywheel is used for converting the kinetic energy to mechanical energy.

Regenerative Braking System

Mr. Shete Prasad Bapusaheb, Mr.Kadam Siddheshwar Madhukar, Mr.Kulkarni Shreyas Rajendra, Mr.Musmade Somnath Sahebrao and Mr. Tathe Pradeep G, IJSRD - International Journal for Scientific Research & Development| Vol. 4, Issue 01, 2016 | ISSN: 2321-0613, pg.853-855 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 rest and the kinetic energy gets wasted due to friction in the form of kinetic energy.

Regenerative Braking System for Series Hybrid Electric City Bus

Junzhi Zhang, Xin Lu, Junliang Xue, and Bos Li, The World Electric Vehicle Journal, Vol 2, Issue 4 pg.128-134, The existing friction based Adjustable Braking System (ABS) on the bus is integrated with each of the new braking systems in order to ensure bus safety and stability. The design of the RBS is facilitated by Simulink which is used to build an interactive, multi-domain simulator that is allows parametric variation of vehicle speed, State of Charge (SOC) for the batteries, and the maximum current to be allowed to the batteries from the RBS.

Research on Electric Vehicle Regenerative Braking System and Energy Recovery

GouYanan International Journal of Hybrid Information Technology Vol.9, No.1 (2016), pp. 81-90, To improve driving ability of electric vehicle, a braking regenerative energy recovery of electric vehicle was designed and the structure of it was introduced, the energy recovery efficiency of whole system was defined and a highly efficient control strategy was put forward, then it was embedded into the simulation of ADVISOR2002

A Study on Control Strategy of Regenerative Braking in the Hydraulic Hybrid Vehicle Based on ECE Regulations

Tao Liu, Jincheng Zheng, Yongmao Su, and Jinghui Zhao, Hindawi Publishing Corporation Mathematical Problems in Engineering Volume 2013, Article ID 208753, pg. 1-9, A mathematic model of composite braking in the hydraulic hybrid vehicle and analyzes the constraint condition of parallel regenerative braking control algorithm

Analysis of regenerative braking efficiency - A case study of two electric vehicles operating in the Rotterdam area

Van Sterkenburg. S., Rietveld. E., Rieck. F., Veenhuizen. B, Bosma. H, 2011 IEEE Vehicle Power and Propulsion Conference, Measurements on a rolling road Dyno test bench will be carried out in order to further verify simulation results and to improve the vehicle model. To analyze the efficiency of regenerative braking, the ratio of brake energy and propulsion energy during the driving cycle, the efficiency of propelling the vehicle and the efficiency of converting brake energy into useful energy

Control of regenerative braking systems for four-wheel-independently-actuated electric vehicles

Jian Chen, Jiangze Yu, Kaixiang Zhang, Yan Ma, Elsevier Journal of Mechatronics 000 (2017) pg.1–8, Control of regenerative braking systems is considered in this paper. Firstly a modular observer is proposed to estimate the vehicle longitudinal velocity, and input-to-state stability theory is utilized to prove that the estimation error converges to zero.

AMT downshifting strategy design of HEV during regenerative braking process for energy conservation

Liang Li a. c, Xiangyu Wang a, Rui Xiong b. c, Kai He a, Xujian Li a, Elsevier Journal of Applied Energy 183 (2016) pg.914–925, for hybrid electric vehicles (HEVs), regenerative braking might be the most effective way of energy conservation. However, the braking energy usually cannot be regenerated completely due to the limit of the motor maximum torque.

Predictive Approaches to Rear Axle Regenerative Braking Control in Hybrid Vehicles

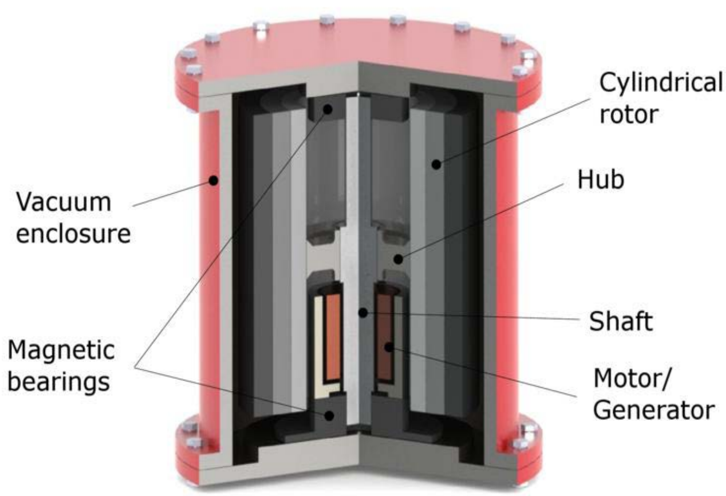
P. Falcone, S. Khoshfetrat Pakazad and S. Solyom, Joint 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference pg.7627-7632, the objective is maximizing the regenerative braking and distributing the friction braking at the four wheels, while *(i)* delivering the braking force requested by the driver, *(ii)* preserving vehicle stability and *(iii)* fulfilling system constraints, e.g., bounds on regenerative braking set by the hybrid powertrain. Two predictive approaches for controlling the regenerative braking at the rear axle in hybrid vehicles

IV. METHODOLOGY

Regenerative Braking System (RBS) (Future of Braking)

Conversion of Kinetic Energy to Mechanical Energy Using Flywheel Energy Storage

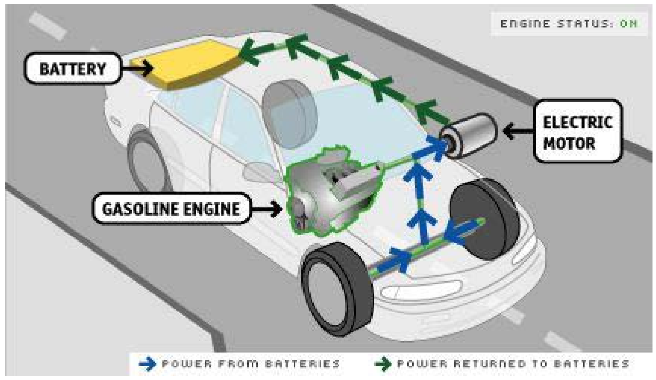
A flywheel is a type of energy storage system which is used to store mechanical energy and then release the stored energy when needed for acceleration. Flywheel is a heavy, high-speed rotating disc that builds up kinetic energy (the force that causes movement) as it spins. The amount of energy stored depends upon how heavier it is and how fast it rotates. Heavier weight and faster rotation results in higher energy storage. We can relate it to a discus thrower in the Olympics. He winds-up, building an increasing store of force and energy as he spins, and then releases the disc and sends it flying through the air. The method of transmission of energy directly to the vehicle is more efficient rather than first storing it in the battery, as it does not consists of the conversion of energies. As, during the recharging of battery, mechanical energy is converted into electrical energy and during discharging electrical energy is converted into mechanical energy. So, due to these conversions transmission loses occur and the efficiency reduces. As, in the other case, there are no transmission loses since mechanical energy stored in the flywheel is directly transferred to the vehicle in its original form. As the energy is supplied instantly and efficiency is high, these types of systems are used in F-1 cars.



The Main Components of a Typical Flywheel

Conversion of Kinetic Energy to Electrical Energy Using Electric Motor

The most common form of regenerative brake involves using an electric motor as an electric generator. The working of the regenerative braking system depends upon the working principle of an electric motor, which is the important component of the system. Electric motor gets activated when some electric current is passed through it. But, when some external force is applied to activate the motor (during the braking), then it behaves as a generator and generates electricity.



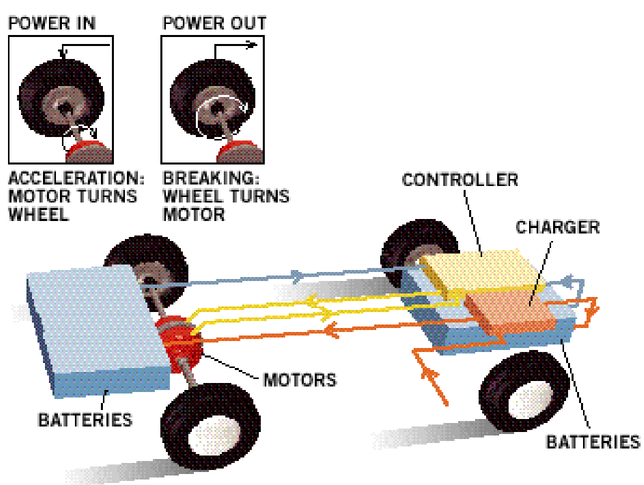
Energy Flow Diagram of A Regenerative Braking System

This means that whenever motor runs in one direction, the electric energy gets converted into mechanical energy, which is then used to accelerate the vehicle and whenever the motor runs in opposite direction, it performs functions of a generator, which then converts mechanical energy into electrical energy, which makes it possible to utilize the rotational force of the driving axle to turn the electric.

Regenerative Braking System

Start prime mover motor. This drives the spur pinion and gear arrangement and there by the brake drum is rotated.

When brake lever is pressed. The plate cam rotates. This drives the roller followers to move radially out in the slots provided in holder plate. This brings the brake friction rollers in contact with the brake drum…The rollers absorb the kinetic energy and start rotating at high speed. This makes the planet gear to rotate the sun gear. Sun gear which is fastened to the main shaft or flywheel shaft thus rotates the fly wheel. The flywheel absorbs this sudden burst of rotational energy and keeps on rotating.



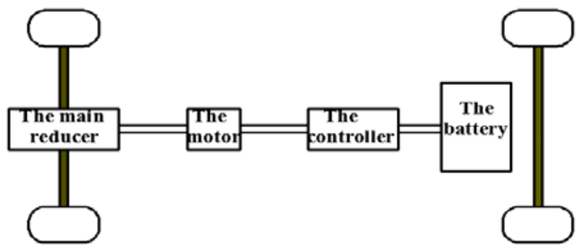
Components of Regenerative Braking System

Rotational power in the flywheel is transferred from the flywheel to the dynamo via spur gear ring mounted on flywheel and spur pinion mounted on the dynamo shaft.

Dynamo shaft rotates to convert this rotational energy into electrical energy which can be stored in battery for further use.

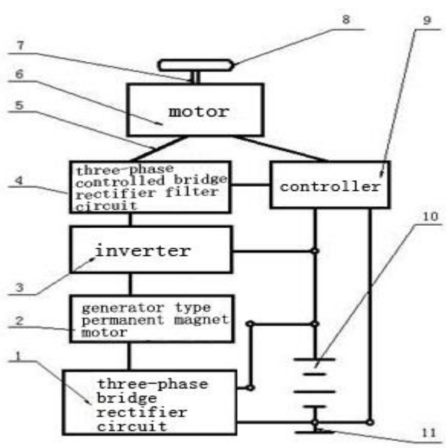
Research on Electric Vehicle Regenerative Braking System and Energy Recovery

Front-wheel drive vehicle regenerative braking structure diagram. When the electric vehicle spending up, the motor controls the current output by the battery through the sensor signal, and then its speed is adjust for providing power. The motor becomes generator when electric vehicle braking, transmits the electric power which is converted by the motor to the battery, recharging the battery. Energy recovery system working schematic diagram. The hardware structure includes permanent magnet motor, controller, three-phase controlled bridge rectifier filter circuit, inverter, three-phase bridge rectifier circuit and so on. When the control signal changes from 1.0 V to 3.5 V, the controller controls permanent magnet motor rotating work, driving vehicle, when the value below 1.0 V, control energy recovery system works and generates electromagnetic braking force and finally realizes the driving wheel braking.



Front Wheel Drive Vehicle Regenerative Braking System Structure Diagram

The specific work flow for the electric vehicle energy recovery system is that the controller controls the permanent magnet motor together with three-phase controlled bridge rectifier filter circuit working through wire connection, the rectifier filter circuit converts the three-phase alternating current produced by the permanent magnet motor to direct current, and then the direct current is delivered to the inverter. Power batteries control the output frequency of inverter through feedback signals; the inverter controls permanent magnet motor to rotate and produces three phase alternating current which is converted into direct current through rectifier circuit at last.



Energy Recovery System Working Schematic Diagram

1- three-phase bridge rectifier circuit; 2- power type permanent magnet motor; 3- inverter; 4- three-phase controlled bridge rectifier filter circuit; 5- three-phase line; 6-magnet motor; 7-shaft; 8- vehicle driving wheels ; 9-controller; 10-power battery; 11- negative grounding end.

Regenerative Braking System

Regenerative Braking Using Flywheel

Flywheel is a heavy rotating mass that stores the kinetic energy or the mechanical energy of rotating wheel in the same form (rotational energy).This process of recovering energy is more efficient. The losses involved during energy transformation are avoided, because the energy is being transmitted in the mechanical form throughout the cycle. In case of recovering the energy through motor/generator and battery system, energy losses occurs as mechanical energy is being transformed into electrical energy while charging the battery and during discharging electrical energy gets converted into mechanical form.

$E= \frac{1}{2} Iw^2$

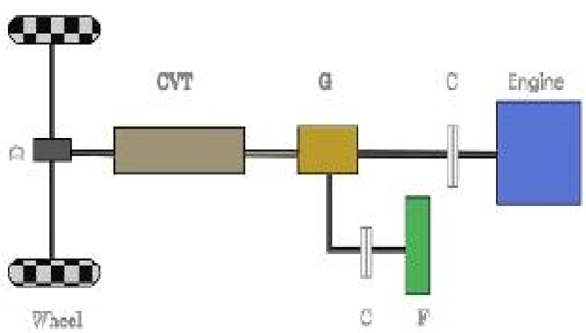
Where, E=rotational energy of flywheel

I=moment of inertia of flywheel

w=angular velocity of flywheel

The amount of energy stored by flywheel depends upon its mass, radius and rotational velocity. Thus, the maximum energy stored by flywheel can be enhanced by increasing moment of inertia and angular velocity of flywheel. In order to recover energy or to initiate energy transfer through flywheel, angular momentum must be varied. For varying angular momentum, angular velocity or moment of inertia must be varied continuously. Thus a Continuous Variable System (CVT) is used to transmit the power. A CVT consist of two pulleys which are connected through belt.

Flywheel-Regenerative Braking System



F - Flywheel , C - Clutch , G - Gear Train , D - Differential

V. DISCUSSION

Mechanical friction brakes exert mechanical resistance to the rotating wheels, which results into a deceleration and a standstill of the vehicle eventually. It was stated above that regenerative braking technologies do brake vehicles by building up different resistances; however, no detailed information has been given so far. This chapter gives insight into the existing technologies for regenerative braking systems, their components, and advantages and disadvantages. First, an overview about the different technologies is given. Second, the basic regenerative braking technologies are presented in detail. Then, few mixed regenerative braking technologies are mentioned. Last, a comparison of the most common regenerative braking technologies is carried out.

FUTURE SCOPE

Kinetic energy recovery system can be used on hybrid gas/electric automobiles to recoup some of the energy lost during stopping. By this way we could save energy every time while braking so there would not be any need of the energy from the engine which would increase its fuel efficiency. And after taking a lot of vehicles into consideration there would be a lot of fuel savings as well as less pollution. So there could be advantages like

1. Less fuel consumption
2. Less pollution
3. After making it in mass production cost will be reduced

Although regenerative braking is more efficient than conventional braking, it is still not popular as electric vehicles and hybrid electric vehicles are still in developing phase. Energy stored in battery can be used to operate air conditioning, lights, mobile charging etc. Besides increasing efficiency of vehicle it increases its weight too that problem can be overcome by using light materials for regenerative circuit components. As our future vehicles will be having electric and hybrid vehicles, regenerative braking system is going to be next revolution in braking system

ADVANTAGES

- Better Performance.
- Cuts down on pollution related to supply generation.
- Efficient Fuel Economy–The fuel consumption is reduced, dependent on the machine cycles, vehicle design, automation control plan, and the individual component’s efficiency.
- Reduced wear and tear of Engines.
- Reduced Brake Wear– Cutting down the replacement brake linings cost, the cost of labor for installation, and machine downtime.
- Reduced emissions–Cuts down on pollution related to power generation, engine decoupling reduces the total number of revolutions and thus engine emissions.
- Smaller accessories – downsizing fuel tank and thus the weight of the vehicle.

DISADVANTAGES

Disadvantages Regenerative braking offers many advantages. However, also potential disadvantages do exist, which are described in this chapter. First, a regenerative braking system cannot fully replace friction brakes. Three main reasons are known for this, including the fact that the wheel torque capacity of electric motors is commonly less than the one for friction brakes. Additionally, the ability of regenerative braking to control the braking force distribution is limited and the time response of charging systems is restricted. Second, a size constraint is known for cars. Regenerative braking systems must be designed as small as possible, yet efficient enough. Third, added extra components increase the weight of the vehicle. This is especially crucial for hybrid vehicles, as several parts must be complemented and fuel consumption is generally increased with the weight of the vehicle, offsetting the actual benefits of the RBS. Fourth, as mass production is not yet standard for regenerative braking systems, significant expenses for planning, manufacturing and installation arise.

Next, there is a safety concern with energy storage of high energy density, but which is desired for an efficient RBS. Passengers must be protected and the chance of dangerous failure must be minimized.

APPLICATION

- Kinetic energy recovery mechanism.
- Regenerative braking systems are used in electric elevators and crane lifting motors.
- Also used in electric and hybrid cars, electric railway vehicles, electric bicycles, etc.
- Could be used in an industry that uses a conveyor system to move material from one workstation to another and halts at ascertain distance after a prescribed interval.

VI. CONCLUSION

The energy lost during the braking is conserved by the regenerative braking system. These systems can work at the high-temperature ranges and are highly efficient when compared to the conventional brakes. Regenerative brakes are more effective at higher momentum. The more frequently a vehicle stops, the more it can benefit from this braking system. Large and heavy vehicles that movies at high speeds builds up lots of kinetic energy, so they conserve energy more efficiently. It has broad scope for further advancements and the energy conservation. Enhances the growth of the economy

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