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Regenerative Braking System is Emerging Technology to Recover Waste Energy

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***Abstract* - In the recent years, the limited amount of fossil fuels and strict emission regulations needs to improve automobile vehicles efficiency. Regenerative braking systems have the potential to improve the fuel economy of vehicles by recovering waste braking energy operating in urban sectors. It is one of the emerging technologies for automotive industry which can convert the most of vehicle kinetic energy during braking into useful energy, stored in a short term storage systems. This energy is converted back into kinetic energy and used to accelerate the vehicle. The buses, taxis, delivery vans, cars have more potential for economy. In this paper the author discussed various systems of the kinetic energy recovery in form of mechanical energy by using flywheels, hydraulic energy by using accumulator and electrical energy by using capacitor and high voltage battery.**

***IndexTerms* - Regenerative Braking system, Flywheel, Hydraulic Hybrid Drive, Electrical Vehicles**

I. INTRODUCTION

According to thermodynamic first low, the energy can neither be created nor be destroyed. It can be just converted from one form to another. So when our vehicle decelerates, its kinetic energy converted in the form of heat and wasted in conventional vehicle during braking. The solution of this problem is Regenerative Braking System. This is one of the emerging technologies for automotive industry which can convert the some portion of vehicle kinetic energy during braking into either mechanical energy, hydraulic energy or electrical energy. This produced energy can be stored as mechanical energy in flywheels, hydraulic energy in accumulator or as electrical energy in the high voltage battery, which can be used again by the vehicle during acceleration. The energy storage unit must be compact, durable and capable of handling high power levels efficiently.

In the recent years due to the energy crisis and environmental pollution, researchers have studied the feasibility of hybrid power trains incorporating regenerative braking system which have the potential to improve the fuel economy of vehicles operating in urban sectors. 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. The buses, taxis, delivery vans, cars have more potential for energy conservation and economy. Therefore, reduced fuel consumption, improved vehicle efficiency and reduced gaseous emissions including CO_2, NOx and particulates matters are the major driving forces behind commercial considerations of regenerative braking systems.

The magnitude of the portion available for energy storage varies according to the type of storage, inertia weight, drive train efficiency and drive cycle. The effect of regenerative brakes is less at lower speeds as compared to that at higher speeds of vehicle. So the friction brakes are still needed in a situation of regenerative brake failure, to stop the vehicle completely..

II. MECHANICAL SYSTEM FOR KINETIC ENERGY RECOVERY

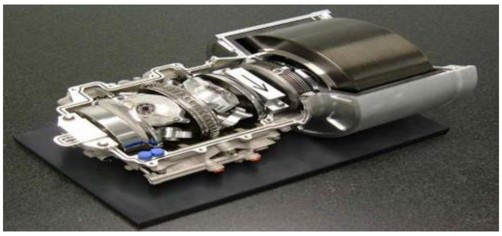

Figure 1: Flywheel for Kinetic energy recovery system of vehicle

The mechanical system utilises flywheel to recover and store a moving vehicle’s kinetic energy which is otherwise wasted during deceleration. The concept of transferring the vehicle’s kinetic energy during braking to Flywheel was postulated by Richard Feynman in the 1950.

Flywheel is a heavy, high-speed rotating. 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. During the braking of vehicle, the flywheel stores the vehicle’s kinetic energy in the form of potential energy. During the acceleration of vehicle, Flywheel acts as a generator and discharges the stored energy to the wheels. Fig. 1 shows a flywheel, made from steel and carbon fiber which rotates at 60,000 RPM and transmits 60 kW power in either storage or recovery mode with 400 kJ usable storage energy capacity. 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 method of transmission of energy directly to the vehicle is more efficient rather than first storing it in the battery. 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.

III. HYDRAULIC HYBRID VEHICLES

Hydraulic Hybrids use three main components to power a vehicle at slow speeds and to augment the gasoline engine. Fluid is stored in a low-pressure reservoir. A pump transfers the fluid from a low-pressure reservoir to a high-pressure accumulator. The accumulator holds this fluid and pressurized nitrogen gas which is used for propeller of vehicle.

Two types of Hydraulic hybrid systems are used. (1) Parallel Hydraulic Hybrid drive and (2) Series hydraulic hybrids drive.

(1) Parallel Hydraulic Hybrid drive

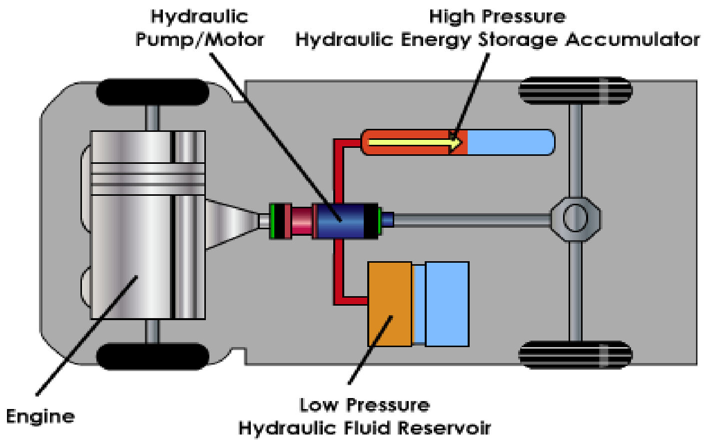

Figure 2: Parallel Hydraulic Hybrid Drive

As the vehicle slows, the pump is activated by regenerative braking and transfer fluid from a low-pressure reservoir to a high-pressure accumulator. As pressure in the accumulator builds, then its sends its energy directly to the driveshaft. Therefore the vehicle accelerates and the pump moves the fluid back to the reservoir.

In a parallel hydraulic hybrid drive, simply connects the hybrid components to a conventional transmission and driveshaft as show in fig. 2. This allows the system to assist the gasoline engine in acceleration only; it doesn't allow the gasoline engine to shut off when the vehicle is not in motion. That means the vehicle is always burning the fuel. This is the main disadvantage compared to electric hybrids but it has significant benefits to increase in fuel economy up to 40 percent. These are used in heavy-duty delivery vehicles only and not for a passenger cars.

Hydraulic Launch Assist

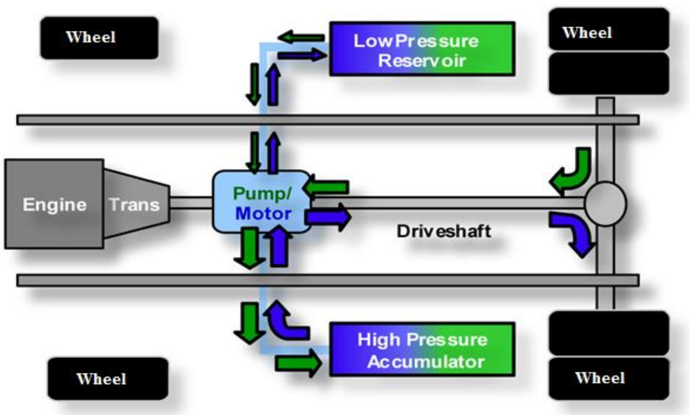

Figure 3: Hydraulic Launch Assist (HLA) System

The Hydraulic Launch Assist (HLA) System is a parallel hybrid hydraulic regenerative braking system developed by EATON as show in fig.3. This system is capable of recovery the majority of the energy normally wasted as heat during braking and uses it to supplement the engine's power during acceleration.

The HLA have two different modes (a) Regeneration mode and (b) Launch Assist Mode.

Regeneration Mode

During braking, the vehicle's kinetic energy drives the pump/motor as a pump, transferring hydraulic fluid from the low pressure reservoir to the high pressure accumulator. The fluid compresses nitrogen gas in the accumulator and pressurizes the system

Launch Assist Mode

During acceleration, fluid in the high pressure accumulator is metered out to drive the pump/motor as a motor. The system propels the vehicle by transmitting torque to the driveshaft.

Advantages of Hydraulic Launch Assist (HLA) Systems are:

- Its delivers 17-28% fuel economy
- Its Reduces emissions of NOx, particulates, and CO2
- Its Provides more torque for quicker acceleration
- Its Greatly increases brake life

(2) Series hydraulic hybrids drive.

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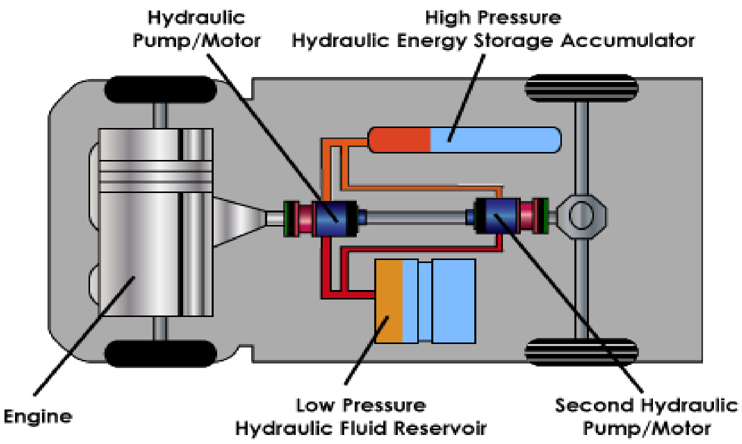

Figure 4: Series Hydraulic Hybrid Drive

Series hydraulic hybrid drive does not use a conventional transmission but transmit power directly to the wheels as shown in fig. 4. As this drive itself turning the wheels, not use a regular transmission of the vehicle's, so that gasoline engine can be shut off, resulting in more fuel savings. With the added efficiency and the ability to shut off the gasoline engine, series hydraulic hybrid drives are capable to improve fuel economy by 60 to 70 percent and reduce environment pollutions.

UPS Truck with Series Hydraulic Hybrid drive

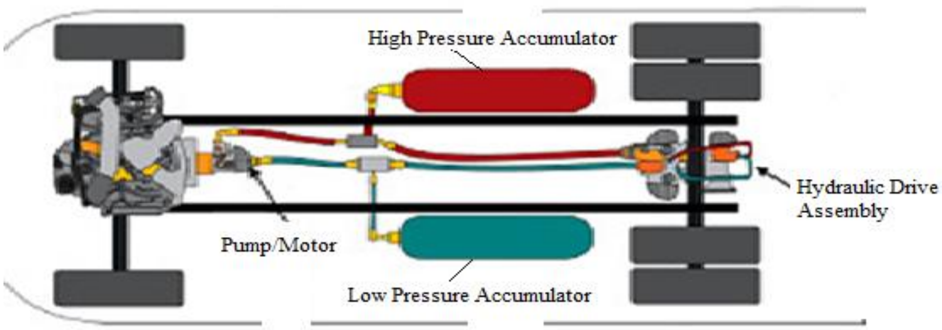

Figure 5: Series Hydraulic Hybrid drive UPS Truck

The system used in UPS truck is a series hydraulic hybrid drive. In this type of system the driveline is replaced by the hybrid system. The transmission is removed and energy is transferred from the engine to the drive wheels through fluid power as show in fig. 5. Fuel economy improvements with this technology are significantly higher than those attainable by the HLA system. UPS trucks go from one stop to the next, often in urban traffic. This vehicle was first shown publicly in June 2006. The series hybrid hydraulic drive UPS truck demonstrated 50-70% better fuel economy than a standard UPS truck with no degradation in performance. The EPA estimates that CO2 emissions from hydraulic hybrid drive UPS trucks are 40 percent lower than conventional UPS trucks. Also it's required less maintenance.

IV. Regenerative Braking Systems for Electrical Vehicles

Before The electric motors in Electrical Vehicles (EVs) and Heavy Electrical Vehicles (HEVs) can be controlled to operate as generators to convert the kinetic of the vehicle into electric energy that can be stored in the high voltage battery and reused.

In Electrical Vehicles, the main three brake control systems are used for Regenerative Braking which is: (i) Series Braking (ii) Parallel Braking and (iii) Electronically Braking Controlled with ABS.

(i) Series Braking Systems

In Series Braking Systems with optimal braking feel, when the braking force demanded is less than the maximum braking force produce by generator, only electrically regenerative braking will apply. When the commanded braking force is greater than the available regenerative braking force, the electric motor will operate to produce its maximum braking torque and the remaining braking force is met by the mechanical brake system. The maximum regenerative braking force produced by generator is closely related to its speed. The control objective of this system is to minimize the stopping distance and optimize the driver's feel.

(ii) Parallel Braking Systems

The parallel brake system includes both regenerative brake and mechanical brake, which produce braking forces parallel and simultaneously in vehicles. It has a mechanical brake which has a fixed ratio of braking force distribution on the front and rear wheels, where as regenerative braking apply additional braking force to the front wheels only. The mechanical braking forces are proportional to the hydraulic pressure in the master cylinder. The regenerative braking force is a function of vehicle deceleration. When the braking deceleration commanded is less than a given value, only regenerative braking is applied.

The parallel braking system does not need an electronically controlled mechanical brake system. A pressure sensor senses the hydraulic pressure in the master cylinder, which represents the deceleration. Compared with the series braking, the parallel braking system has a much simpler construction and control system. However, the driver's feeling and amount of energy recovered are compromised.

(iii) Electronically Controlled Braking Systems with ABS.

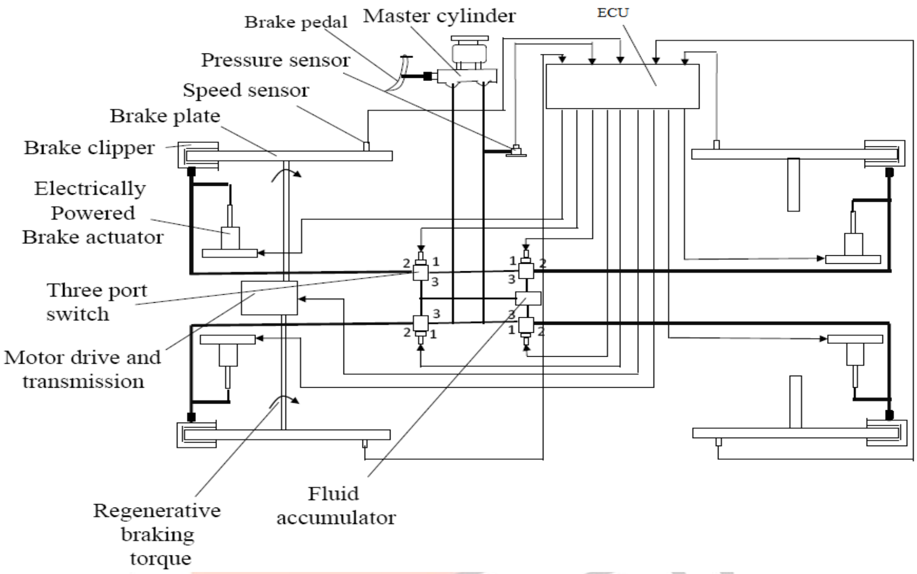

Figure 6: Line diagram of electronically controlled regenerative braking system acts as ABS.

The control of generator braking torque of a regenerative braking system is easier than the control of the mechanical braking force. Thus, antilock braking system is more advantageous in EVs. Fig. 6 illustrates a simple diagram of electronically controlled regenerative braking system, which acts as an ABS. The main components of antilock braking system are the brake pedal, master cylinder, electronically controlled brake actuators and three-port switches, fluid accumulator, pressure sensor and electronic controller unit (ECU).

The pressure sensor measures the fluid pressure according to the driver's desirable braking force. The fluid is discharged into the fluid accumulator through the electronically controlled three-port switches. After receiving a braking pressure signal, the ECU determines regenerative braking torque and mechanical braking torque, according to the traction motor characteristics and control rule. The motor controller commands the motor to produce correct braking torque and the mechanical braking controller commands the electrically powered braking actuator to produce correct braking torques for each wheel. The braking actuators are also controlled to function as an antilock system to prevent the wheels from being locked completely.

If an electrically powered braking actuator is detected to be a failure, the corresponding three-port switch closes port 3 and opens port 2 and then fluid is directly discharged to the wheel cylinder to produce braking torque. The control strategy is crucial for energy recovery and braking performance.

V. ADVANTAGES OF REGENERATIVE BRAKING SYSTEMS

- After Increase overall energy efficiency of a vehicle.
- Reduced emission of CO_2, particularly in urban traffic situation.
- Breaking is not total loss because it converts most of waste energy in to useful work.
- Improved vehicle performance.
- Reduction in engine wear.
- Increase in engine life
- Increases the lifespan of friction braking systems due to reduction in brake wear.
- The range of electrical vehicle increased

VI. LIMITATIONS OF REGENERATIVE BRAKING SYSTEMS

- The Increases complexity of brake control systems.
- Friction brakes are still necessary for safety of passengers in the event of failure of the regenerative brake.
- Extra components can increase weight of vehicle.
- Added maintenance requirement as per complexity of design.
- The main constraint for cars is size of energy storage system.
- Its effect drops off at lower speeds; therefore the friction brake is still required to complete halt the vehicle.

VII. APPLICATION OF REGENERATIVE BRAKING SYSTEMS

- To recovering most of kinetic energy of vehicle which is otherwise lost during braking.
- It is used in some elevator and crane hoist motors.
- The buses, taxis**,** delivery vans, cars have more potential for regenerative braking.
- It is also used in conveyer belt which is frequently starts and stop in manufacturing industries.

VIII. CONCLUSION

When vehicles are driving with a stop-and-go pattern in urban areas, a significant amount of energy is consumed by frequent braking, which results in high fuel consumption. The braking energy in typical urban areas may reach up to more than 25% of the total traction energy. In large cities, such as New York, it may reach up to 70%. It is concluded that effective regenerative braking can significantly improve the fuel economy of vehicles. Alternative sources state that the addition of regenerative energy storage systems to motor vehicles can achieve theoretical fuel savings of up to 23% in a 1600 kg vehicle on a level road urban driving schedule. A 1000 kg vehicle can achieve theoretical savings of 15%. Research by Volkswagen has shown that a hybrid drive with both electric drive and I.C.Engine offers potential fuel saving of over 20% compared with purely electric. In futures, the efficient utilization of energy will be a major challenge. Regenerative braking system is able to reduce fuel consumption in hybrid vehicle and lower the environment pollution. By developing new capacitor, which has frequent charging and discharging capacity with compact and durable high voltage battery and electronics control system more braking waste energy can be recover in future.

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