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# Design and Fabrication of Hydraulic Regenerative Braking System

**Yash Bavishi[1], Kunjan Chauhan[2], Vedant Mardia[3] and Paresh Patel[4]**

*[1-4]B.Tech. Student, Department of Mechanical Engineering, Indus Institute of Technology & Engineering, Indus University, Ahmedabad, India*

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**Abstract -** This study examines the implementation of a regenerative braking system for vehicles based on hydraulics. The regenerative braking system can capture and recycle the generally wasted braking energy during a vehicle drive cycle. This report presents a model of a novel configuration for hydraulic regenerative braking systems, deliberates several parameters of the components and their effects. This report primarily focuses on the implementation of a hydraulic regenerative braking system on a bicycle. The purpose of implementing this system is to decrease the human effort required for driving a bicycle through a regenerative braking system as it can store and reuse the energy that is otherwise lost due to the conventional braking. The impetus for regenerative braking is improved efficiency for automobiles, which in turn would reduce greenhouse gas emissions and decrease the reliance on fossil fuels.

## I. INTRODUCTION

Regenerative braking is an energy recuperation mechanism, which slows down a vehicle or object by converting the kinetic energy into a form, which can be used immediately or stored until needed. This is in contrast to the conventional braking systems, where excess kinetic energy is converted into unwanted heat and dispersed by friction in the brakes, or with dynamic brakes, where energy is recovered using electric motors as generators but is immediately dissipated as heat in the resistances. In addition to improving the overall efficiency of the vehicle, it can significantly extend the life of the brake system, as its parts do not wear out as quickly. Regenerative braking is a technology that stores energy by slowing down a body and makes that energy available for reuse. With traditional friction brakes, a body's kinetic energy is wasted 100% as the heat dissipates into the surrounding environment. Commonly, regenerative braking has two main forms: Hydraulic and Electric. Electrical systems use generators to convert kinetic energy into chemical potential energy through batteries. Hydraulic systems use pumps to convert the kinetic energy into mechanical potential energy by pressurizing an incompressible fluid.

The increase in car use has been observed over the decades. This has led to the development of several new methods in a car to improve various factors and comfort. But we see that the pollution emitted by the automotive sector has increased significantly as most of the carbon monoxide emissions were due to car use. In addition, fuel shortages have been increasing day by day due to the use of motor vehicles. This results in the governments of several countries raising the price of fuel, implementing strict laws to reduce the emission of pollution from a vehicle. This results in the development of several new methods to improve the emission of pollutants in terms of fuel efficiency by various companies and individuals. Over the decade, methods such as electric cars, cars powered by alternative fuels and the reduction of losses that occur in the normal car are applied and improved. The driving force behind regenerative braking is greater automobile efficiency, which in turn would reduce greenhouse gas emissions and decrease dependence on fossil fuels. One of the methods which is the Regenerative Braking System (RBS) can eliminate the losses normally found in conventional braking.

In Hydraulic Regenerative Braking System (HRBS), we work on the phenomenon of hydraulics and braking is carried out on this principle with the help of the hydraulic fluid, which is used to compress the nitrogen present in the accumulator. The hydraulic motor is powered by the residual kinetic motion of the vehicle which has pressurized the fluid. In short, the accumulator acts as an energy storage device. This energy can be reused at any time to help accelerate the vehicle.

Basically, in every HRBS system, the main components are the accumulator, the hydraulic motor pump, the storage tank, the manifold block and the flow control valves. The variation of these components makes it possible to apply the hydraulic regenerative braking system to almost all vehicles, from bicycles to trucks. This gives HRBS a wide range of applications that other systems lack.

### A. Types of Regenerative Braking Systems: -

There are several methods of converting energy into RBS, including spring, flywheel, electromagnetic, and hydraulic. More recently, an electromagnetic flywheel hybrid RBS has also emerged. Each type of RBS uses a different energy storage or conversion method, providing variable efficiencies and applications for each type. Currently, the most used type is the electromagnetic system.

1. **Electromagnetic:**
   In the electromagnetic system, the vehicle's crankshaft is connected to an electrical generator that uses magnetic fields to limit the rotation of the crankshaft, slowing the vehicle and generating electricity.

2. **Flywheel:**
   In the RBS flywheel, the system collects the vehicle's kinetic energy to spin a flywheel that is connected to the driveshaft via a transmission and gearbox. The rotating flywheel can supply torque to the driveshaft, giving the vehicle a boost of power.

3. **Electromagnetic flywheel:**
   The regenerative electric flywheel brake is a hybrid model of electromagnetic and RBS flywheel. Share the basic methods of energy generation with the electromagnetic system; however, energy is stored in a flywheel rather than batteries. In this sense, the steering wheel acts as a mechanical battery, where electrical energy can be stored and recovered. Due to the longevity of the flywheel battery compared to lithium ion batteries, the RBS electric flywheel is the most cost-effective method of accumulating electricity.

4. **Spring:**
   The spring-loaded regenerative braking system is typically used on human-powered vehicles such as bicycles or wheelchairs. In the RBS spring, a coil or spring is wound around a cone during braking to store energy in the form of an elastic potential. The potential to assist the driver when climbing or over rough terrain can then be restored.

5. **Hydraulic:**
   Hydraulic RBS slows the vehicle by generating electricity which is then used to compress a fluid. Nitrogen is often chosen as the working fluid. Hydraulic RBSs have the longest energy storage capacity of any system, as the compressed fluid does not dissipate energy over time. However, compressing the gas with a pump is a slow process and severely limits the power of the hydraulic RBS.

**B. The main advantages of regenerative braking systems can be summarized as:**

- Improved fuel economy: Depends on duty cycle, powertrain design, control strategy and individual component efficiency.
- Reduction of emissions - Engine emissions are reduced by disconnecting the engine, reducing overall engine revolutions and overall engine running time (engine ON/OFF strategy).
- Improved performance.
- Reduced engine wear: engine start and stop strategy.
- Reduced brake wear, reduced brake lining replacement costs, reduced installation labor and vehicle downtime.
- Smaller Accessories - Hybrid powetrain offers the ability to eliminate (electric starter) or downsize (fuel tank) some accessories, thus partially offsetting the increase in vehicle weight and cost due to hybrid hardware additions.
- The range is comparable to that of conventional vehicles, a problem that electric vehicles have not yet overcome.

## II. DESIGN OF HRBS

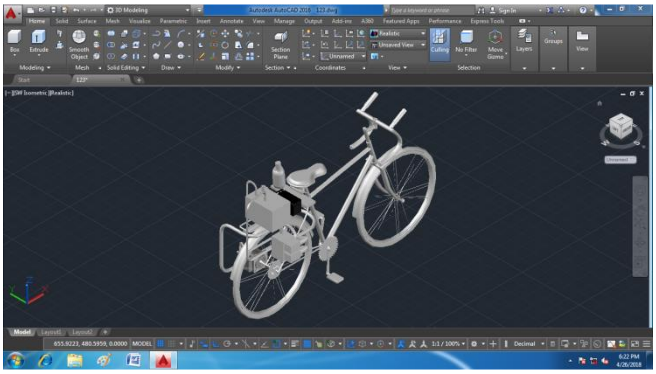

Fig.1 3D view of bicycle in Auto-CAD

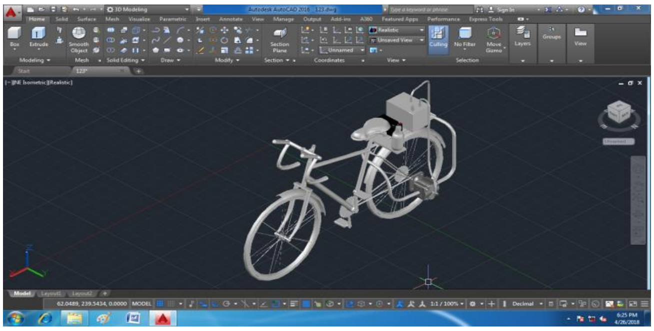

Fig.2 Another 3D view of bicycle in Auto-CAD

The figure above shows the arrangement of the main components on the bicycle frame. A tank (R) is connected to the vertical element of the frame. The pump (P) is connected to the gear wheel with the help of the gear arrangement. The accumulator can be connected to the horizontal element of the frame and the hydraulic motor (M) is connected to the rear wheel with the help of a gear arrangement. The arrangement of the valves and the electronic control system is not shown in the figure for simplicity. The hydraulic system consists of many components such as a pump, valves, motor, accumulators, etc. The different functions of the regenerative system can be controlled by an electrical system as all valves are operated by solenoids.

Fig.3 Actual Prototype

Above is the actual prototype that was built and used for performing tests.

## III. WORKING OF THE HRBS

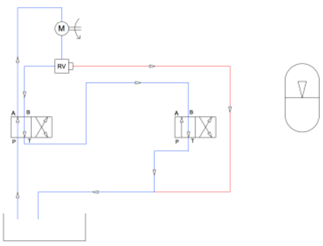

Fig.4 Pedaling mode

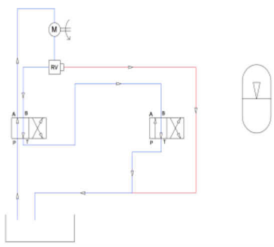

Fig.5 Cruising mode

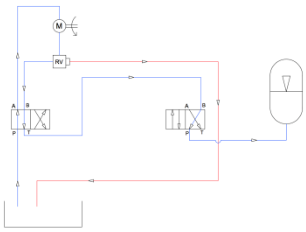

Fig.6 Braking mode

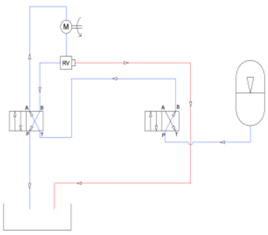

Fig.7 Launch mode

The full ride of a bicycle can be classified into 4 basic modes such as pedal mode, non-pedal or cruise mode, brake mode and launch mode. In pedal mode, the power supplied by a human is used directly to propel the bicycle. In cruise mode, the bike maintains its motion by inertia. In the case of the braking mode, the momentum of the bike is used to operate the pump, which in turn fills the accumulator, and in the case of the launch mode, the energy stored in the accumulator is used to drive the bike and earn momentum without human effort. These different modes can be obtained with the help of the actuation of different valves in the hydraulic circuit.

In pedaling mode, the power delivered by the cyclist is delivered directly to the pump, this is achieved by directing the pump to the gear located in the bearing block which is connected to the main gear present in the center of the rear wheel axle. When there is no brake or launch mode, both valves are not receiving electricity, which means they are in a closed position, which is indicated in position 1 in the table. Then the engine runs but the valves do not allow the flow of fluid to the accumulator, it makes it pass to the low storage tank. There is a certain amount of power loss due to continuous engine operation that is neglected. Since the efficiency of the engine is high, it is not a burden to the rider.

**Table 1:** Actuation Of Valves For Different Modes

| Valve Actuation for different modes | | |
|---|---|---|
| Mode | Valve 1 | Valve 2 |
| Pedalling mode | OFF | OFF |
| Cruising mode | OFF | OFF |
| Braking mode | ON | OFF |
| Launch mode | ON | ON |

In no pedaling / cruising mode, the bicycle maintains its movement without pedaling due to the moment of inertia of the vehicle and the cyclist, in some cases going down the slope of the road in this mode both valves are closed, as in the previous mode.

In braking mode, the motors are connected to the accumulator with the help of the opening valve 1. This is operated with the help of the battery and the switches on the steering rod. When the rider operates the brake switch, valve 1 opens and the circuit is formed to the accumulator. The low-pressure oil in the reserve is drawn into the engine through the valve and the pressurized engine oil is sent to the accumulator. During braking mode, the hydraulic motor acts as a pump, which pressurizes the fluid. The energy needed to drive the motor is drawn from the kinetic energy of the bicycle, causing the bicycle to decelerate. that is, brake the bicycle. After the accumulator is completely filled, the excess oil is discharged into the tank (R) through the pressure relief valve (Rv).

During launch mode, accumulator oil is sent to the hydraulic motor by opening valve 2. This valve is battery operated and switch operated and the switch is known as the launch switch. It runs the hydraulic motor and propels the bike with the help of attached gears. The energy stored in the accumulator is converted into kinetic energy. After the engine rotation is complete, the low pressure oil from the engine is returned to the reservoir.

## I. LIST OF THE COMPONENTS

**Table 2:**

| Quantity | Part Description | Company Name | Description of the Component |
|---|---|---|---|
| 2 | Directional valve | Rexroth solenoid valve 4WE6 | Controls the direction of the flow of the fluid. |
| 1 | Diaphragm Accumulator | Hydac diaphragm Accumulator 1.4 ltr | Stores the regenerative energy and supplies when needed. Recharged nitrogen can be up to 90 bars. Capacity if 1.4 Litre. |
| 1 | Hydraulic Gear motor | Honor 12 cc/rev 12MM1U0 | The hydraulic motor pump which displaces the fluid. Pressured it. the rating is 12 cc/rev. |
| 1 | Low pressure tank | MS low pressure tank | Stores the low-pressure fluid and supplies when needed. Capacity 6 litre. |
| 1 | battery | Solance batter 12.5 v 7.5mA | Battery to provide current to operate the valves. |
| 2 | Gear and chain | Bicycle Gear and chain | Provides motion from the Cycle wheels to the gear motor. |
| 2 | Light switch | Anchor 120V switch 50 Hz | Provides the mechanism to operate the valve according to our needs. |

## II. CALCULATIONS OF HRBS

### A. Theoretical readings

The distance supposed to be travelled by the bicycle can be found out with the help of following parameters

D is the displacement of the Motor which is 9 cc/rev
The actual amount of the fluid flowing in LPM varies upon the RPM of the hydraulic motor which varies according to speed so assumptions are made

Now considering for,
1)For 50 bar pre-charging pressure,
Now at 1000 rpm we get 9 LPM
So, at actual LPM of the accumulator, we need x amount of Rpm

(1000 x 0.7)/9
Therefore x=77.77 rpm
Now the Rpm available at the wheel we get
N(wheel)=77.77/3=25.92 RPM

Now the distance travelled by the circle can be found out by multiplying the Circumference of the wheel with RPM of the wheel

Distance travelled by the cycle = $\pi$x Diameter of wheel x N(wheel)
D=3.14x70x25.92
D=5697.216 cm
Therefore, the circle theoretically will travel 56.97 m without considering the losses.

2)For 55 pressure bar
We get 0.62 LPM. Substituting the value Iin equation (a) we get
$N_{Motor}$=66 Rpm
$N_{wheel}=N_{Motor}/ 3$=22.2 Rpm
Now distance Travelled by the Cycle
$D=\pi d_{wheel} \times N_{wheel}$
D=3.14x70x22.2
=4881.45 cm
Therefore, the circle theoretically will travel 48.97 m without considering the losses.

3)For 60 pressure bar
We get 0.55 LPM. Substituting the value in equation (a) we get
$N_{Motor}$=61.05 RPM
$N_{wheel}=N_{Motor}/3$= 20.35 Rpm
Now distance travelled by the cycle
$D=\pi d_{wheel} \times N_{wheel}$
D=3.14x70x20.35
D= 4472.67 cm
Therefore, the circle theoretically will travel 44.72 m without considering the losses.

4)For 65 pressure bar
We get 0.5 LPM. Substituting the value in equation (a) we get
$N_{Motor}$=55.5 RPM
$N_{wheel}=N_{Motor}/3$= 18.5 Rpm
Now distance Travelled by the cycle
$D=\pi d_{wheel} \times N_{wheel}$
D=3.14x70x18.5
D= 4066.78 cm
Therefore the circle theoretically will travel 40.66 m without considering the losses.

5)For 70 pressure bar
We get 0.45 LPM. Substituting the value in equation (a) we get

$N_{Motor}$=48.85
$N_{wheel}$=$N_{Motor}$ /3= 16.65 Rpm
Now distance Travelled by the cycle
$D=\pi d_{wheel} \times N_{wheel}$
D=3.14x70x16.65
D= 3659.43 cm

Therefore, the circle theoretically will travel 36.59 m without considering the losses.

**Table 3:** Theoretical Readings

| No. | Pre-charging pressure | LPM in accumulator | RPM | | Launch Distance in M |
|---|---|---|---|---|---|
| | | | $N_{Motor}$ | $N_{wheel}$ | |
| 1 | 50 | 0.7 | 77.71 | 25.9 | 56.98 |
| 2 | 55 | 0.62 | 66 | 22.2 | 48.45 |
| 3 | 60 | 0.55 | 61 | 20.3 | 44.72 |
| 4 | 65 | 0.5 | 55.5 | 18.5 | 40.72 |
| 5 | 70 | 0.45 | 48.5 | 16.65 | 36.59 |

### B. Experimental Analysis

The experiments are conducted considering the following conditions: the longitudinal speed of the bicycle is 20 km / h. The total weight of the bicycle and the adult cyclist is 100 kg. The transmission ratio is 1: 3. The accumulator used is a membrane accumulator of 1.4 liter capacity. During the experiment, the volumetric efficiency of the pump is considered to be 95%, this is possible since the pump will operate at low pressure and low rpm. Changing the pressure of the pre-charged nitrogen gives the following results.

**Table 4:** Actual Readings

| No. | Pre-charging pressure | Stop distance | Launch distance |
|---|---|---|---|
| 1 | 50 bar | 29 m | 55 m |
| 2 | 55 bar | 27 m | 47 m |
| 3 | 60 bar | 24 m | 43 m |
| 4 | 65 bar | 23 m | 39 m |
| 5 | 70 bar | 21 m | 35 m |

### C. Results

**Table 5:** Torque Relation To Pre-Charging Pressure

| Pre- charging Pressure | Torque (Nm) | Stopping Time (sec) | Deceleration $(m/s^2)$ |
|---|---|---|---|
| 50 | 54.6 | 4.46 | 3.043 |
| 55 | 65.02 | 3.92 | 2.8 |
| 60 | 73.4 | 3.8 | 2.92 |
| 65 | 78.3 | 3.4 | 3.56 |

## III. CONCLUSIONS

The hydraulic hybrid technology has the advantage of a high power density and the ability to accept high speeds / high frequencies of loading and unloading, making it very suitable for off-road vehicles and heavy trucks. But the lower energy density requires a special energy control strategy for HRBS.

The first thing to say is the loss of maneuverability of the vehicle when the system is pressurized. Some improvements need to be made if hydraulics are to be used on steering wheels or tipper vehicles.

Although the operation of the system by the driver with the foot lever was quite good, in future applications this lever should be lowered. To be ergonomic and fully utilized, the system must be electronically operated so that the driver does not have to think about which brake or accelerator to use. Furthermore, the lever can be released in time to avoid a reversal of the work cycle or too high pressures on the low pressure side of the system.

The behavior of the system was really smooth and pleasant to use. Braking and acceleration changed progressively as the pressure increased or decreased but always smoothly. For this reason, an alternative braking system was needed for harder or emergency brakes.

To be able to use this system in future applications, the stored energy must be used when the vehicle is already in motion and the driver wants to accelerate it further. Otherwise, the vast majority of energy is wasted in the work of non-conservative forces.

## IV. SCOPE AND OBJECTIVES

Regenerative braking systems require more research to develop a better system that captures more energy and stops faster. As time goes by, designers and engineers will perfect regenerative braking systems, so these systems will become more and more common. All moving vehicles can benefit from these systems by recovering the energy that would have been lost during the braking process, thus reducing fuel consumption and increasing efficiency. Future technologies in regenerative braking will include new types of engines that will be more efficient as generators, more powerful batteries that can withstand more frequent charging and discharging, new transmission designs that will be built with regenerative braking in mind, and less prone to electrical systems. energy losses. Of course, problems can be expected as any new technology is refined, but only a few technologies have greater potential for improving vehicle efficiency than regenerative braking.

## V. REFERENCES


A. David M. Swain; Jason Z. Moore; Frank C. Maurer; Albert Shih, "HYDRAULIC REGENERATIVE BRAKING SYSTEM FOR VEHICLE", EPA, US7,992,948 B2, Aug. 9, 2011

B. Deepak Vishwakarma; Sayujya Chaurasia, "REGENERATIVE BRAKING SYSTEM", IIJET, Vol-1, issue-1(2016), pp.27-30

C. Yutaka Tamagawa; Mitsuaki Hirakawa, "REGENERATIVE BRAKING SYSTEM", US 6,222,334 B1, Apr.24, 2001

D. Koustuba Dinesh Lagwankar, ""HYDRAULIC REGENERATIVE BRAKING SYSTEM FOR BICYCLE", IJERA, Vol-3, Issue 1, Jan-Feb 2013, pp.869-875

E. ER. Amitesh Kumar, "HYDRAULIC REGENERATIVE BRAKING SYSTEM", IJSER, Vol-3, Issue 4, April-2012

F. Yasushi Aoki; Ikuo Nonaga; Yasushi Suganuma, "COMBINED HYDRAULIC AND REGENERATIVE BRAKE SYSTEM IN AN ELECTRIC VEHICLE", US 5,857,755, Jan. 12, 1999

G. Abhishek G. Pathak; Bhagwat D. Ghodke, "HYDRAULIC REGENERATIVE BRAKING SYSTEM", IJRAT, Special Issue National Conference "CONVERGENCE 2017", 9th April 2017

H. Rama R. Venkataperumal; Gerald E. Mericle, "COMBINED HYDRAULIC AND REGENERATIVE BRAKE SYSTEM", US 4,270,806, Jun. 2, 1981

I. Dale Crombez; Patric Curran; Steven Napier, "HYBRID ELECTRICAL VEHICLE POWERTRAIN WITH REGENERATIVE BRAKING", US 2005/0151420 A1, Jul. 14, 2005

J. Xavier Guinart Trayter; Jordi Orpella Aceret, "HYDRAULIC REGENERATIVE FOR LIGHT VEHICLES", Linkoping University, SE-581 83 Linkoping Sweden, LIU-IEI-TEKA-A-10/00890-SE

K. Sachin Chouhan; Sanjiv Kumar; Krishna Veer Choudhary; Kuldeep Singh, "REGENERATIVE BRAKING SYSTEM FOR BICYCLE", IJIR, Vol-3, Issue-7, 2017

L. Setyamartana Parman; Eijaz Zainuddin, "DESIGN AND ANALYSIS OF HYDRAULIC IN A HEAVY COMMERCIAL VEHICLE BY RECOVERING ENERGY DURING BRAKING", ARPN Journal of Engineering and Applied Sciences, Vol-11, NO. 20, Oct. 2016

M. Tri-Vien Vu; Chih-Keng Chen, "STUDY OF HYDRAULIC REGENERATIVE BRAKING SYSTEM IN HYDRAULIC HYBRID VEHICLES", Journal of Science and Engineering Technology, Vol-7, No.4, 2011

N. Xiaobin Ning; Yangyan Guo, "RESEARCH ON ELECTRIC HYDRAULIC REGENERATIVE BRAKING SYSTEM OF ELECTRIC BUS", MEMS 2012