HRB – Hydrostatic Regenerative Braking System: The Hydraulic Hybrid Drive from Bosch Rexroth

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Executive Summary

In times of high oil prices, increasing environmental awareness all over the world and global urbanization resulting in strict emissions legislation, fuel-saving technology in vehicle drive systems becomes increasingly attractive for private and public operators. HRB, the hydraulic hybrid of Rexroth, reduces fuel consumption and CO₂ emissions from heavy commercial vehicles with a high stop & go frequency by up to 25 percent and brake wear by up to 50 percent. This helps to reduce environmental pollution and the total cost of ownership for the operator. After successful field testing, which started in July 2008 in Berlin and New York, the HRB system is now going into series production.

Introduction

Heavy commercial vehicles, with a high stop & go frequency like refuse trucks or parcel delivery vehicles, produce in a short time a huge amount of energy. This energy, which is generated via a high load on the combustion engine during the acceleration, is converted into wasted heat and given off, “unused” into the environment, when the vehicle brakes again. This, in comparison to other commercial vehicles, leads to an above-average higher fuel consumption, as well as wear on the brakes. To reduce brake wear, an additional retarder could be integrated. However, this does not lead to a reduction in fuel consumption. This was the basic idea of the HRB system. HRB decreases the load on the brakes during deceleration, and the load on the combustion engine during acceleration, leading to a considerable reduction in fuel consumption and brake wear.

HRB System Components

The HRB system components, suitable for refuse trucks with a gross vehicle weight between 18t and 26t are based on serial production components which Rexroth has been producing since years. This ensures good availability, reproducible quality and a system lifetime on vehicle level.
HRB system components: A4VSO axial piston unit with gearbox, accumulator, valve control block with accumulator safety valve, electronic controller

A HRB consist of:

A4VSO: Variable axial piston unit for pump/motor operation with a displacement of 210 ccm, a maximum power of 233 KW and a max. torque of 1.113 Nm => Multiplied by the HRB gearbox ratio and the rear axle ratio (based on Daimler Econic, Daimler Actros and MAN TGS) would result in a maximum brake and acceleration torque of approximately 10.000 Nm on the wheels.

Gearbox: Three different ratios are available (1.5; 2.2; 3.2), synchronized for the common rear axle ratios of the truck chassis manufacturers to achieve the best system efficiency and the highest fuel savings.

Accumulator: High pressure bladder accumulators with an integrated nitrogen bladder, is compressed during braking and relaxed when the vehicle needs to accelerate again. The charging pressure is at 120 bar and the maximum pressure at 325 bar. In the current HRB system, two bladder accumulators with each 32l volume are integrated. In both accumulators up to 0,15 KWh can be stored, accordant to the kinetic energy from braking of 30 km/h down to 0 km/h minus all losses (rolling friction, aerodynamic resistance, etc.).

Valve control block: The hydraulic control unit of the HRB system controls the flow of oil and ensures through a pressure control valve that at no given time excess pressure occurs in the system.

Electronic controller: Our control strategy is found in here. The electronic control device ensures that the HRB runs safely, efficiently and comfortably at all times. The goal is to reduce as much work for the driver as possible and at the same time maximize savings.
Sensors: Over 10 different sensors (i.e. pressure, temperature and speed) ensure that the electronic control device is kept up-to-date on all system conditions.

**The Hydrostatic Regenerative Braking System (HRB)**

The hydraulic hybrid is ideal for vehicles using conventional mechanical drive trains and a combustion engine, as with refuse trucks and heavy delivery vehicles.

A gearbox connects a hydraulic variable axial piston unit to the mechanical drive train (drive shaft) to convert kinetic energy into hydraulic energy when braking. The axial variable piston unit operates as a pump and converts kinetic energy into hydraulic energy by loading a hydraulic bladder accumulator with hydraulic fluid and brakes the vehicle. This process is controlled by an electronic controller from Rexroth together with a hydraulic valve manifold.

![Image of the Hydrostatic Regenerative Braking System](image)

*When braking, the variable axial piston unit converts kinetic energy into hydraulic energy and pumps hydraulic fluid into a bladder accumulator filled with Nitrogen*

During acceleration the entire process is reversed: The pressurized fluid is discharged in a controlled manner from the accumulator and flows back through the variable axial piston unit. The latter is driven by the fluid flow and, acting as a motor, gives up its energy to the mechanical drive train and relieves the existing combustion engine. A pressure relief valve and an electronic monitoring of all safety relevant system (i.e. pressure) and vehicle (i.e. ABS/ASR) variables, ensures the highest level of safety for both processes.
During acceleration the pressurized hydraulic fluid in the accumulator drives the variable axial displacement unit, which then works as a motor.

**HRB System Savings Potential**

The HRB system saves up to 25 percent fuel in a refuse truck collection cycle or during urban driving and almost doubles the lifespan of the driving brake. These 25 percent savings are based on a combination of different stop & go distances (from 10m to 100m) and a waiting period of 30 seconds after each stop. It was driven by a 20t refuse truck on our test grounds in Ulm/Elchingen (20t = average load of a three-axel refuse collector).

![Graph showing fuel savings at different driving distances](image-url)

*Fuel savings at different driving distances*
Furthermore, the HRB system was tested on its efficiency, independently of Bosch Rexroth by the ADAC Driving Safety Centre in Berlin-Brandenburg. ADAC (Independent German Automobile Association) got the following results:

“During test runs, under daily conditions, the hybrid drive HRB showed a fuel savings potential in an average of minimum 20 percent. It can even be assumed that there is a considerable reduction in wear on the brakes, since the “loading” of the HRB accumulators brakes the vehicle. Special strengths of the hybrid drive are especially illustrated during short stops on slight inclinations, since these, with charged hybrids, are completely driven with the hydraulic motor. This in turn leads to a very strong fuel savings.

Further advantage is the reduction in all harmful substances found in the exhaust, especially sooty particles. These are produced strongly during extreme acceleration of the vehicle (engine under full load). During this phase, the HRB system relieves the combustion motor. It must be assumed that the reduction in sooty particles lies well above the 25 percent fuel savings.

Why a Hydraulic Hybrid

A hydraulic hybrid is ideal for heavy vehicles in stop & go operation. The reason for that, is the possibility to save in a hydraulic accumulator high energy flows in a short time (high power density). With a similar electric battery, this is not possible. In the same short time, this battery can only store a small portion of the energy flow in comparison to a hydraulic accumulator (see picture). With lithium ion batteries, the matter is even more complicated. Over time the so-called “memory effect” takes place, which reduces the storage capacity and limits the lifespan of the battery.

![Graphs showing storage loading speed vs. brake energy for different vehicles: Refuse Truck, Delivery Vehicle, Passenger Car.](image)

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Speed Range</th>
<th>Acceleration</th>
<th>Graph Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refuse Truck</td>
<td>25 to 10 km/h, 1.5 m/s²</td>
<td></td>
<td>Only the hydraulic accumulator is sufficient fast to absorb the complete breaking energy</td>
</tr>
<tr>
<td>Delivery Vehicle</td>
<td>7 to 30 km/h, 2.5 m/s²</td>
<td></td>
<td>The hydraulic accumulator is suitable and the lithium battery can largely recover the braking energy</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>1.5 to 50 km/h, 2 m/s²</td>
<td></td>
<td>The Lithium Battery fits well, however the lead battery is never sufficient to recover a part of the braking energy</td>
</tr>
</tbody>
</table>

**Hydraulic Bladder Accumulator, Lithium Battery, Lead Battery and real Breaking Energy**

**Storage Loading Speed vs. Brake Energy**
In today’s electric hybrid systems for heavy commercial vehicles the batteries must be replaced after 3-4 years, which calls for extra work and extra costs. This replacement is not needed with a hydraulic system. All main components are designed to the lifespan of the vehicle. The components require only little maintenance effort, which can be handled, even today, by a vehicle workshop with experience with implement hydraulics. However, this isn’t granted for an electrical hybrid with his 400 – 900V on-board voltage.

**HRB Costs**

HRB is based on proven production and close-to-production components. Nevertheless, these are not catalogue products, so that no general selling price can be published. The actual added value lies in the combination of these components into a system, i.e. in the Rexroth know-how for configuring the hydraulic hybrid for the respective vehicle class the driving strategy. The (added) price for the HRB as part of the respective project situation is derived based on these and other vehicle-specific requirements. Vehicle operators demand amortization times of less than four years.

**HRB in Practice**

The first refuse truck equipped with HRB was introduced to the public by Rexroth at the IAA Commercial Vehicles exhibition in September 2008. Two years later in September 2010, after successful field testing in several cities in Germany and the United States, the German testing agency for technical inspection TÜV granted single vehicle approval to vehicles equipped with hybrid drives from Rexroth according to Section 21 of the StVZO (traffic regulations). This TÜV seal of approval plus single vehicle approval verify the high safety level of our hydraulic hybrid drive and opens the way for series deployment of the environmentally friendly HRB technology. Currently such vehicles with the Rexroth hybrid on board are in operation in over ten cities. The official start of production was October 2010.
The HRB hydraulic hybrid from Rexroth is already in series use in over 10 cities

One of the first customers is the regional Sanitation Department of the District of Kassel. Carsten Mielke, Head of Department for Transport, is convinced of the system’s benefits. “Our refuse collection vehicles consume clearly less diesel fuel than vehicles without HRB. Over an entire route we are seeing savings from 15 to 18 percent.” This is enough, according to Mielke, to justify the acquisition of additional vehicles with the hydraulic hybrid. Another customer of the first round was the Sanitation Department of Kiel. After thorough testing they decided to purchase vehicles equipped with HRB technology. “The City Council of the state capital Kiel has set environmental protection as a priority, and we as a municipal entity want to do our part to achieve these objectives, HRB makes an important contribution to environmental and climate protection” explains Sigfrid Schock, Head of Department Sanitation Logistics and Technology. Two vehicles are already in service on Kiel streets, and the procurement of additional trucks with the Rexroth hybrid is planned. As Sigfrid Schock summarizes: “The HRB is the right step in the right direction.”

Conclusion

The hydrostatic regenerative braking system (HRB) from Bosch Rexroth is an economically meaningful and environmentally friendly possibility for heavy commercial vehicles in stop & go operation to reduce the fuel consumption and increase the lifetime of the disc brakes. Through the use of production-oriented components in connection with an intelligent control, this system, is integrable in a vehicle, with manageable additional expenses. Furthermore, it has proven its use and suitableness for mass production through a test phase over years, as well as the TÜV certification as according to Section 21 StVZO. The hydraulic hybrid is available for series as of October 2010.