Feasibility of a Regenerative Braking System for a School Bus

by

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Feasibility of a Regenerative Braking System on a School Bus

A Thesis Proposal by

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Objective

The goal of this thesis is to determine the feasibility of a regenerative braking system (RBS) on a school bus and to subsequently develop and test a prototype system.

Motivation

It is proposed that a regenerative braking system be utilized on a school bus to improve fuel efficiency and reduce exposure of children to diesel particulates. The primary benefit of a RBS is a decrease in the amount of fuel used to drive the bus. The advantage of using less fuel is a decline in emissions. Previous studies conducted at Clarkson University have shown the level of exposure to tailpipe emissions that is experienced by children on a school bus. [1]

The characteristic stages of driving a vehicle to its destination combine to create the vehicle’s mission. First the car is started and then accelerated to speed. Acceleration of a vehicle is an extremely inefficient process; when a vehicle is accelerated, a large amount of fuel is consumed to increase the speed of the vehicle. After acceleration, the vehicle may stop and go through red lights, or idle in city traffic, but eventually it comes to a halt at its destination. The braking process of a vehicle is the most wasteful task, from an energy perspective. When a vehicle decelerates, all the kinetic energy that has been built up through acceleration is lost to heat, in a matter of seconds through friction. This cycle of starting and stopping is magnified by a school bus, whose average number of stops is much higher than that of a typical car driving down the road.

Background

A regenerative braking system is a set braking and energy storage system that is typically installed in parallel with conventional brakes. Conventional brakes are left on a vehicle for emergency or high speed braking situations where the RBS has not yet proved reliable rapid response time. The idea of a RBS on vehicles is not new, and has been researched and installed on different vehicles with varying degrees of success for the past 50 years. Four common types of regenerative braking systems are electric motor/generator pairs, flywheels, compressed air, and hydraulics. It is also possible to create a RBS from an arrangement of different technologies. In Germany in the 1970’s they developed the Hydrobus, which utilized a combination of flywheels and a hydraulic pressure tanks for its RBS with more success than a single standing technology. [2]

New hybrid cars are built with both a regenerative braking system and a conventional braking system in parallel. A parallel system of brakes frequently becomes too complex for a mechanical braking system alone. In many new hybrids, electronic braking control has been added to handle the complexities of two braking systems in combination with safety features like anti-lock brakes. A hybrid’s RBS operates by switching an electric motor to a generator upon braking. This energy is then stored in either a capacitor or battery system. Upon acceleration, energy from the reservoir is used to start the electric motor. [3] The 2008 Nissan Altima is an example of a handful of hybrids that has this technology installed on the vehicle. Below is a concept image for the Nissan RBS.
This method of an electric RBS is also used on electric trains and trolleys throughout the world, and has been for over 40 years. Virgin Trains, for example, claims an energy savings of 17% for their Pendelino’s in the U.K with this system in place. [5]

An alternative type of RBS system operates using a flywheel storage strategy. This type of storage has been used as far back as the middle of the 19th century in steam engines that helped to bring about the Industrial Revolution in America. First proposed for vehicles by physicist Richard Feynman in the 1950’s, flywheels have been used in different vehicle components. In the 1990’s Jack Bitterly and his company U.S. Flywheel Systems created the first flywheel engine to make competitive, gasoline free cars. [6]. Flywheels were prominent in the 1960’s when they were implemented on gyrobus in Yverdon, Switzerland. The gyrobus system is a flywheel rotating on either mechanical or magnetic bearings in a vacuum chamber. The flywheel is connected to an electric motor/generator for storage and reuse of energy. The drawback of a braking system that utilizes a flywheel is the additional weight, which costs energy to carry around. Another type of flywheel developed for diesel buses is a Band Variable-Inertia Flywheel (BVIF), which has shown an improved fuel savings of 30% and a brake wear reduction by a factor of five in comparison to other flywheel models. [7]. A Kinetic Energy Recovery System (KERS), the newest design on the market, is the specific term applied to flywheel storage in Formula One racing, where they were implemented in vehicles during the 2009 competition season. [8]

A third method of storing energy in a vehicle is a compressed air storage system. This system operates either exclusively air power, or by air power in combination with gasoline, diesel, or electric motors. A Homogeneous Charge Compression Engine (HCCI) engine is typically required in these vehicles to act as the air compressor. A computer simulation of a modified and hybridized internal combustion engine has been created to operate regenerative braking cycles. Engine valves are actuated to generate the torque necessary to run a RBS. [9]. In some cases, a pneumatic device is used to switch valves and store air in a reservoir during the braking process.

The final form of RBS technology already in use is a Hydraulic Launch Assist (HLA). This system, produced by Eaton Power Corporation, has been used by Ford Motor Company on their largest F-350 models. The basis of an HLA system is to use a hydraulic fluid as the working
fluid for compression upon braking. It can be used in accordance with an accumulator and gas filled bladder that becomes compressed for storage, or with a mechanical spring. Currently, Eaton Power Corporation is looking to adapt this system to hybrid waste collection vehicles. They claim that on their Roadranger model they have seen a 15-30% increase in fuel economy, a reduction in emissions, and a break life that has more than doubled. [10]

![HLA System on a Refuse Truck](image)

**Figure 2: HLA System on a Refuse Truck [11]**

### Methodology

Four RBS designs will be preliminarily analyzed as possible prototypes for the school bus. These designs are: electric motor/generator storage, flywheel storage, pneumatic device for compressed air storage. In order to accurately analyze these systems, specific information about how a school bus operates will be required.

The National Renewable Energy Lab has produced a program suitable for vehicle modeling and simulation software to aid in design and production of prototypes. The program is ADVISOR2002 (Advanced VehIcle SimulatOR), essentially a set of MatLab/Simulink text files, models, and experimental vehicle data compiled in the 1990’s for research purposes. For user defined inputs, ADVISOR is capable of modeling a vehicle to study the fuel economy, energy usage, emissions, transmission, and powertrain systems. [12] The following preliminary questions will be answered via the computer simulation:

- How much energy/power does a bus dissipate upon braking?
- How much energy/power is required to bring the bus back up to speed?
- Distance required to bring a bus to a complete stop.
- How much diesel is used during an average stop-and-go drive cycle?
- What are the expected emissions of a stop-and-go drive cycle?
Taking into considerations the needs of a system based on the ADVISOR model, each preliminary design system will be analyzed on the following considerations:

- Size of each system needed to store the braking energy
- Added weight considerations of each system
- Efficiencies
- Energy density
- Ease of a retrofit
- Estimated cost
- Energy cost of added system

The design will be optimized and a prototype constructed for testing purposes. A school bus has a significant amount of space under the carriage that remains widely unused. If a retiring school bus from a local public school cannot be borrowed for testing, then the prototype system could be run on the dynamometer at Clarkson University. The prototype will be tested for a decrease in fuel usage and an estimate of decreased emissions will be determined. It is hoped that a successful strategy will be found whereby a repeat set of tests could be conducted to compare the effectiveness of the RBS.

**Preliminary Results in ADVISOR2002**

A trial run of ADVISOR was conducted to learn how the program operates. ADVISOR hosts numerous kinds of transit buses that it is able to model. A transit bus is defined as a public transportation bus for short distances. Transit buses are larger than a school bus and weigh on average 40,000lbs. [13] For a conventional, automatic transmission, transit bus, the following graph is an output by the simulation of the drive cycle.

![Figure 3: Requested vs. Actual Drive Cycle](image)

In Figure 3 the actual trace, in red, is the simulation of a defined drive cycle. The requested trace by the user, in blue, is the simulation that ADVISOR was asked to run. The actual trace follows almost identically to the requested drive cycle. Through time, there is an increase and a decrease of the bus from 0-55 mph. This correlates to different areas of acceleration and braking. Accordingly, the simulation records expected acceleration and braking energies for this drive cycle. Figures 4 and 5 are graphical representations of this energy data.
The acceleration energy is highest when the vehicle is accelerating to its maximum speeds throughout the drive cycle.

In juxtaposition to the acceleration energy, the braking energy that is lost is the highest when the bus brakes from the maximum speeds. The braking energy is also less than the acceleration energy by about 50 KJ. There are losses of efficiency throughout the drive system as a vehicle is
accelerated. Therefore, it requires more energy to accelerate a bus than the energy lost from the system in braking.

These two energy cycles will be compared for a school bus drive cycle, which will be modeled to incorporate proper speed, sizes, and cargo masses. The emissions from a drive cycle will also be simulated for a diesel bus. From this information, the regenerative braking systems will be sized and their feasibilities examined.

**Expected Results**

Although, it is yet unclear which of the systems or combination of systems has the potential to be the most effective regenerative braking system on a school bus, it is not unreasonable to anticipate that there is a significant amount of energy to be recaptured from a braking vehicle. The conventional school bus is a Type C bus which is built upon a flat-back cowl chassis. [14] This bus type is a Class 7 school bus, and on average weighs 29,500 lbs. [15] If, for example, the 29,500 lb bus is moving at 30 mph and brakes to a stop. The kinetic energy associated with the moving vehicle is:

\[
\text{Ideal maximum amount of energy lost} \approx 1,201 \text{ KJ.}
\]

The numbers from the above simulation take into account inefficiencies in the cycle; the energy lost from the above simulation is 170 KJ and the energy required for acceleration is 210 KJ. This means that 81% of the energy used to accelerate the vehicle comes from the RBS. The increase in fuel efficiency would be measured through a lower consumption of diesel to power the bus.

If the system is able to propel the vehicle forward with the engine initially off the highest amount of emissions would not be released during acceleration. Assume that the average bus stops 15-20 times during its daily route. Considering that there are approximately 450,000 school buses in the United States alone, the overall reduction in diesel emissions would be remarkable. [16]

**Proposed Timeline**

<table>
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<tr>
<th>Date</th>
<th>Goals</th>
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| April 1, 2010             | ● School Bus Data Collection  
<pre><code>                      | ● Define Inputs                                                      |
</code></pre>
<p>| Spring 2010               | ● Continuing Literature Search on Four Proposed Systems             |
| May 2010                  | ● Perform School Bus Simulation                                    |
| Summer 2010               | ● Analyze Possible Systems                                          |
|                           | ● Choose a System                                                   |
|                           | ● System Optimization                                               |
| September-October 2010    | ● Design/Construct a Prototype System                               |
| November-December 2010    | ● Test Prototype System                                             |</p>
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<tr>
<th>January 2011</th>
<th>● Finish Results Analysis of Prototype</th>
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<td>February 15, 2011</td>
<td>● Finish First Draft of Thesis</td>
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<tr>
<td>March 2011</td>
<td>● Submit Final Draft of Thesis</td>
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<td>April 2011</td>
<td>● Oral Presentation and Final Thesis</td>
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References


