IPRO It takes a team INTERPROFESSIONAL PROJECTS PROGRAM

IPRO 342 Fall 2006

Mid-Term Progress Report

Hybrid Electric School Bus: Simulation, Design & Implementation

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Introduction

IPRO 342 was created to evaluate the suitability of hybridizing a school bus by constructing and testing a scaled down model of a hybrid electric school bus. Conventional vehicles use internal combustion engines to drive them. Although the internal combustion engine performs very well at constant speeds, its efficiency at varying speeds is extremely poor. An electric machine, however, can be much more efficient and environmentally friendly in such conditions. Unlike conventional vehicles, hybrid electric vehicles utilize both an electric machine and an internal combustion engine to propel them in a manner that is more fuel efficient and environmentally friendly. In fact, hybrid electric vehicles attain the higher fuel economies than conventional vehicles when operated in driving conditions that involve many halts. Since school buses halt frequently, they are ideal candidates for hybridization.

In order to demonstrate the superior fuel economy of a hybrid electric school bus, and to improve and standardize it, the development of a test bed was deemed necessary. While there are several software programs already in use that evaluate the fuel efficiency of automobiles, most of them are unable to fully model all of the details and functions of a hybrid electric vehicle.

While deciding on the scope of IPRO 342, it was also determined that the school bus should be converted into a parallel hybrid electric vehicle system (i.e., combining the internal combustion engine and electric machine output into the drive shaft). Previous hybrid electric vehicle research has shown that there are some difficulties with the series hybrid electric vehicle system (i.e., coupling a generating electric machine and the internal combustion engine to drive an outputting electric machine). These include loss of power in multiple conversion locations, higher cost, and lesser flexibility. One of the major advantages of a parallel HEV system is the ability to run on the internal combustion engine, the electric machine, or both depending on the driving conditions.

Once IPRO 342 was started, its specific objectives and the methods by which these objectives were to be achieved were decided upon. Some of these objectives were met using the project plan developed, but some changes also had to be made to the project plan. The achievements made to date, the issues that led to changes in the project plan, and the changes themselves are discussed in the following sections of this report.

1.0 Revised Objectives

IPRO 342's objectives have not been altered greatly from those stated in the project plan report. This semester, IPRO 342 aims to design a test bed for a scaled down model of a hybrid electric school bus, and build a dynamometer to test the model of the bus. However, the original objective was to design a test bed for a one-eighth scale model of the school bus. It was later discovered that a one-eighth scale model would be too large for safe testing, so the scale of the model was changed such that the maximum electric motor size required would be 3 kW. The electrical and mechanical sub-teams have designed their sections of the test bed accordingly, and have decided on what components will need to be ordered by next semester's team in order to build the test bed.

The next task is to construct a dynamometer to quantify the performance of the scaled down hybrid electric bus when it is tested next semester. The dynamometer will consist of electric motors that will measure the power output of the hybrid electric bus, and sensors that will measure other parameters such as torque output and engine speed. The mechanical team will design the electric motor mounts such that vibrations will be reduced to a minimum, and decide how to incorporate the other sensors into the test bed. The electrical team will design electronic control circuits for the dynamometer's motors and sensors using dSPACE.

2.0 Results to Date

Both the mechanical and electrical teams have been effective in progressing toward their respective objectives. They have worked hard to complete not only their original goals for the semester but additional goals as well. Originally, the primary goal of the project was to perform background research on the creation of a model hybrid electric vehicle "test bed" to simulate the working components of an actual vehicle. However, the group has also taken on the design of a much smaller scale partial model to be created this semester to demonstrate the feasibility of the "test bed" concept and to develop further knowledge of the testing platforms.

Currently both the electrical team and the mechanical team are working on both the large-scale research and the small-scale model of the test bed. Substantial research has been completed on each of the different aspects of the system as set out in the original block diagram. The primary goal of the large-scale research is to select appropriate components and give a general design for the actual test bed that is to be created next semester, and this has been partially achieved with the creation of preliminary designs and proposals. One of the major successes of the group was the formation of an outline with which to convey all research.

This outline, as attached in appendix A, can be applied to all portions of the system and easily displays the variety of information and options. The format begins with a statement of the problem pertinent to that system, then applicable background research, after which possible solutions are laid out. These possible solutions are then compared to one another to highlight advantages and disadvantages in order to make the ultimate selection of a solution simpler. These comparisons are based on several criteria, including cost, the attainability of parts, system functionality, and the ability of each component to realistically simulate its full-scale counterpart on an actual bus. Finally, the form offers a concluding opinion of what solution would work best for that system and lists sources for future reference. This allows the groups actually building the test bed over future semesters to have on hand not only the recommended components & pricing for each portion of the system, but also the background rationale and other options that could help them to understand the way in which the system should be set up.

Not only has the format been selected for the presentation of the results, but also much of the preliminary research has been conducted. First, a general design has been chosen for the test bed; this will be a parallel setup of components. Next, most of the major components have been selected, even though continuing research will give more solid reasoning as to why these mechanisms are appropriate. There is continuing research being done as to the pricing and scale of the desired apparatus

The block diagram lists seven different sub-systems: battery, electric machine, power electronics, differential gear, drive shaft, power split/coupling, and support frame. Preliminary research has shown the numerous possible options for each of these as well as having determined a “best” choice for each one. For the current selections of each type of system, see chart 1. Further research throughout the semester will finalize these decisions as well as get accurate pricing and vendors for each component.

Chart 1: Current Component Selections	
Component:	Type Chosen:
Battery	Lead Acid Batteries
Electric Machine	Permanent magnet brushless DC motor
Power Electronics	Inverter using an IR2133 chip and MOSFETs
Differential Gear	Single rear differential, conventional
Drive Shaft	Solid stainless steel shaft with multiple universal joints
Power Split/Coupling	Planetary gear-set
Support Frame	Angularly braced stainless steel frame

The other aspect of the project is the small-scale dynamometer model that is being created. This model will take some of the complex electrical systems and model them at a small scale to demonstrate the way they work and how their performance may be optimized. It also provides similar experimental opportunities from the mechanical side with respect to vibration control and mechanical efficiency. Currently the basic electrical designs for the model have been uploaded to iGROUPS, the materials listed and purchased, and the teams have begun building the actual circuitry for the models. An example of an electrical schematic has been included in Appendix B. This schematic is of the inverter system that enables the dSPACE to control the location of the poles, and thus the motion of the motor. Additional systems that are being built instead of purchased are the isolator and the current sensor. The mechanical design is partially fixed by the use of on-hand components, with modifications being made to improve and adapt their performance. The plan is to have the circuitry built in the next few weeks so that debugging and preliminary testing can begin. This testing will also provide familiarity with some of the programs that will be used on the larger scale model, such as dSPACE. dSPACE is an important system currently in use for modeling the outputs of such systems as hybrid electrical vehicles. This will enable the results of the system, both on this smaller scale model and on the larger scale model to be read in a fashion that is more readily comprehensible, allowing the actual benefits of the test bed to be easily understood. The small-scale model should be completed, running, and producing results by the end of this semester.

In conclusion, not only will the background research required for next semester to build the test bed be complete, but a small-scale model demonstrating the basic systems will also be completed. The research will be clearly presented in a standard form so that the next team will be ready to purchase parts, build, and begin using the test bed. The current results are applicable to the testing and demonstration of hybrid electrical buses to possible future clients. Preliminary research has suggested that this test bed will be able to model actual systems and will be useful for demonstrating the feasibility of hybridizing school buses.

3.0 Revised Task / Event Schedule

Team	Date	Event or Task
Mechanical	Week 1 – Week 2	• Complete Block Diagram (Mohammed)
	Week 2 – Week 3	• Complete Project Plans (Mohammed, Ali)
	Week 3 – Week 5	• Dyno Frame Design (Joel) • Dyno Drive Shaft Design (Preeti) • Continuously Variable Transmission Demonstration (Mohammed)
	Week 3 – Week 6	• Differential Research Report (Aamer) • Drive Train Research Report (Mohammed) • Driveshaft Research Report (Preeti) • Supporting Structure Research Report (Joel) • Power Split/Coupling Research Report (Jatan, Mohammed)
	Week 7 – Week 9	• Build Dyno Frame, Driveshaft, and Planetary Gear Power Split Device (Aamer, Mohammed, Preeti, Joel, Jatan)
	Week 8 – Week 9	• Troubleshoot and test Dyno Frame, Driveshaft, and Planetary Gear Power Split Device (Aamer, Mohammed, Preeti, Joel, Jatan)
Electrical	Week 1 – Week 2	• Complete Block Diagram (Ali)
	Week 2 – Week 3	• Complete Project Plans (Ali, Mohammed)
	Week 3 – Week 5	• Electric Motor, Isolator and Current Sensor Schematics (Ali, Shan) • Power Electronics and Inverter Schematics (Garrett, Tyler) • dSPACE and Battery (Eric)
	Week 3 – Week 6	• Electric Motor Research Report (Ali, Shan) • Power Electronics Research Report (Garrett, Tyler) • Battery Pack Research Report (Eric)
	Week 7 – Week 9	• Build Isolator, Current Sensor, and Inverter Circuit. Test Connections between dSPACE and Current Sensors (Ali, Shan, Garrett, Tyler, Eric)
	Week 8 – Week 9	• Troubleshoot Isolator, Current Sensor, and Inverter Circuit. Test Connections between dSPACE and Current Sensors (Ali, Shan, Garrett, Tyler, Eric)
Presentation	Week 6 – Week 7	• Determine Presentation Leaders (Ali, Mohammed, Eric, Garrett, Preeti)
	Week 7 - Week 12	• Create Presentation for IPRO Day (Ali, Mohammed, Eric, Garrett, Preeti)
	Week 13	• Practice Presentation (Ali, Mohammed, Eric, Garrett, Preeti) • Finalize and Submit Presentation (Ali, Mohammed, Eric, Garrett, Preeti)

		• Deliver Presentation on IPRO Day (Ali, Mohammed, Eric, Garrett, Preeti)
Poster	Week 6 – Week 7	• Determine Presentation Leaders (Shan, Joel, Jatan, Aamer, Tyler)
	Week 7 – Week 12	• Create Poster for IPRO Day (Shan, Joel, Jatan, Aamer, Tyler)
	Week 13	• Finalize Poster for IPRO Day (Shan, Joel, Jatan, Aamer, Tyler)

4.0 Updated individual assignments and team organization

Since the beginning of the semester when the original project plan was determined there have been few changes that have affected the overall structure of teams and sub teams. The entire IPRO team was divided into two sub teams to make the overall completion easier. These two teams were mechanical and electrical. The mechanical team was in charge of everything that involves the mechanical side of the project. The electrical team was in charge of all electronics including dSPACE which will be used in controlling the final model. These assignments have not changed up to this point. There are still two teams, electrical and mechanical, consisting of 5 members in each team. The current team and sub team responsibilities are as follows:

Team	**Name**	**Responsibility**
Electrical	Ali Gowani	-Electrical Team Leader -Electric Motor
	Tyler Inouye	-Power Electronics
	Garrett Nielson	-Power Electronics
	Sonya Colletti	-Electric Motor -Power electronic isolation -Current Detection
	Eric Hope	-Battery -DSpace
Mechanical	Mohammed Khader	-Mechanical Team Leader -Drive Train/Power Coupling and Splitting
	Preeti Abraham	-Drive Shaft
	Aamer Saeed	-Differential
	Jatan Shah	-Drive Train/Power Coupling and Splitting
	Joel Fenner	-Frame Support

The changes from the original project plan as stated were minimal and only occurred for unavoidable reasons. The original plan was to build a 1/8th scale model of a hybrid electrical school bus to be used for a test bed. After much deliberation this was changed to a dyno model because of the size and safety concerns of a 1/8th scale model. Since this change the mechanical team had to redirect themselves according to the new changes. Another change for the mechanical team was the use of an electric motor to model the internal combustion engine. This was decided due to the ease of controlling an electric motor as compared to that of controlling an internal combustion engine. This also changed sub team member responsibilities.

In terms of changes to the electrical team responsibilities, there have been very few. The original plan of a 1/8th scale was troubling to the team because of size but this was the only concern for the electrical team. The power electronics being built will work for any size of model. The only other change to sub team member responsibilities for the electrical team was for Eric Hope. Eric was initially in charge of only the battery but because of how quickly he finished the research and product selection of the battery, he also undertook the task of dSPACE. dSPACE, while currently assigned to Eric, will eventually become a responsibility of the entire electrical team.

Overall the teams are working well together and much work is being accomplished. The teams are experiencing good team cohesiveness so no changes have had to be made based on conflicts or other such problems.

5.0. Barriers and Obstacles

The project plan for this semester was to give recommendations for a hybrid school bus test bed for a future IPRO and also to create a small scale dyno model. After looking at the work done by previous IPROs and other online sources on hybrid vehicles, the team learned the basic ideas that were needed in order to work on this project.

The major obstacles for the mechanical team were

- Figuring out what to use and how to build the frame of the test bed
- Figuring out what kind of drive shaft to use
- Figuring out what kind of differential gear to use
- Figuring out what kind of power split or coupling to use

The major obstacles for the electrical team were:

- Figuring out what kind of battery to buy
- Figuring out what kind of motor to use as the electric machine
- Figuring out what kind of power electronics were needed

The two teams overcame these obstacles by reviewing previous test bed designs for other scale models and by researching the possible ideas and solutions for each obstacle. The team picked the best solution for each obstacle, gave reasons why that was the best solution, and also researched sources for buying the supplies and their pricing.

The remaining obstacles for the future test bed design will be building the frame, fitment issues of the mechanical components, and then testing the whole design to make sure it works properly. These obstacles will be encountered in the future IPRO and not during this one so it will be handled by the future team when the time comes.

The remaining obstacles for the dyno model are alignment and vibration issues with the motors, building the electrical components, figuring out how to use the computer program for the demonstration, and testing the actual design to make sure it works properly. The team will deal with these obstacles by buying the electrical parts to build the actual electrical components from scratch, the team will use different motors and spend time aligning and testing to decrease the motor vibrations, and the team will also look at the manual and online guides on how to use the computer program for the demonstration.

Appendix A: Example of format for presentation of research.

Battery Pack Research

Problem

To select a battery pack for the hybrid test bed that is able to adequately power the electric motor and fit within our budget

Background Information

Hybrid Electric Vehicles (HEVs) use a conventional car battery as well as a rechargeable battery pack. The conventional car battery maintains the same function in a HEV, starting the vehicle's internal combustion engine. The function of the rechargeable battery pack is to provide power to the HEV's electric motor. Currently, two different types of batteries are available for use in HEV's, Lead-Acid batteries and Nickel Metal Hydride (NiMH) batteries.

Lead-Acid batteries contain electrodes composed of lead metal (Pb) and lead (IV) oxide (PbO_2) and an electrolyte composed of Sulfuric Acid (H_2SO_4) and water (H_20). When the battery discharges, the electrodes become lead (II) sulfate ($PbSO_4$) and the electrolyte becomes primarily water. Conventional Lead-Acid batteries are not designed for deep discharging. These batteries contain a large number of thin electrode plates in order to maximize surface area, thus maximizing output current. The thin plates are damaged by deep cycling. Deep-Cycle Lead-Acid batteries are specifically designed to withstand frequent discharging. The plates of a deep-cycle battery are generally thicker than a conventional Lead-Acid battery, allowing them to withstand deep discharging. However, the increase in plate thickness also decreases the surface area of the plates, resulting in a lower current output. Lead-acid batteries are among the worst batteries in terms of energy-to-to weight ratios. Conversely, due to their ability to supply high currents, Lead-Acid batteries maintain a high power to weight ratio.

Nickel Metal Hydride batteries are rechargeable batteries that use nickel metal for the cathode and a hydride absorbing alloy for the anode. All commercially available hybrid vehicles currently utilize NiMH battery technology for powering their respective electric motors. For example, the Honda Civic Hybrid currently uses 120 NiMH batteries with a rating of 6 Ah to power its 15kW permanent magnet electric motor. NiMH batteries are highly sensitive to overcharging and temperature changes. Overcharging a NiMH battery will result in decreased charge efficiency. NiMH batteries currently have one of the highest energy-to-weight ratios along with an average power-to-weight ratio.

Potential Solutions

The first possible solution would be to use a Lead-Acid battery pack. The battery pack would be composed of several deep-cycle batteries. The rating and number of batteries contained in the battery pack would highly depend on the size of the electric motor selected. Approximately six to ten deep-cycle batteries would be required for this application.

The second possible solution would be to use a NiMH battery pack. The battery pack would be composed of many "small-format" NiMH batteries. The rating and number of batteries contained in the battery pack would highly depend on the size of the electric motor selected. A large number of Ni-MH batteries would be required for this application.

Price Information

Deep-Cycle Lead-Acid Batteries

Model	Rating	Price	Source
Odyssey PC1200	12V, 44Ah	$165.99	batteriesplus.com
Odyssey PC1700T	12V, 68Ah	$239.99	batteriesplus.com
Odyssey PC2150	12V, 95Ah	$261.00	qualitypowerauto.com
Trojan CB24-AGM	12V, 80Ah	$164.95	ebatteriestogo.com
Trojan CB27-AGM	12V, 100Ah	$184.95	ebatteriestogo.com
Trojan CB31-AGM	12V, 110Ah	$215.95	ebatteriestogo.com

NiMH Batteries

Model	Rating	Price	Source
Energizer DNH2 D Cell 2-pack	2,500mAh D 1.2V	$8.99	newegg.com
5010B 10 Cell NiMH C Pack	5,000mAh C 12V	$65.00	onlybatterypacks.com
10010F 10 Cell NiMH D Pack	10,000mAh D 12V	$110.00	onlybatterypacks.com
NiMH Battery Pack DV-HF10R2T-MT	13Ah 12V	$129.95	batteryspace.com
NiMH Battery Pack MHP-48V10Ah-4WR	10Ah 48V	$395.95	batteryspace.com

Pros and Cons

Lead-Acid Battery Pros	Lead-Acid Battery Cons
• Relatively inexpensive compared to NiMH batteries • High power to weight ratio • Readily Available	• Energy-to-weight ratio (~30Wh/kg) • Energy-to-size ratio (~65Wh/L) • Price of single battery around $200 • Short Lifespan (3-4 years or about 200 charges) • Slow to charge (~5-10 hours) • Size and Weight (~50lbs)

NiMH Battery Pros	**NiMH Battery Cons**
• Energy-to-weight ratio (~60Wh/kg) • Energy-to-size ratio (~100Wh/L) • Long Life (~10 years and thousands of charge cycles) • Quick charge capabilities	• Self Discharge Rate (30% per month at 20C) • Requires a "smart" charging device to avoid overcharging • Must be in a temperature controlled environment • Very expensive compared to Lead-Acid batteries (~5-10 times more expensive)

Conclusion

A Lead-Acid battery would prove to be the best choice for the hybrid school bus test bed. Even though they are rather large and heavy as compared to NiMH batteries, Lead-Acid batteries would provide plenty of power to the electric motor. Currently, Lead-Acid batteries are also much more affordable than NiMH batteries. Finally, the purpose of the test bed is to provide a lower bound for the efficiency of a hybrid electric school bus. Since the use of NiMH batteries would provide increased efficiency over Lead-Acid batteries, a lower bound to efficiency would be provided with the use of Lead-Acid batteries.

Sources

"Deep Cycle Battery FAQ." *Northern Arizona Wind and Sun*. Retrieved September 11, 2006, from http://www.windsun.com/Batteries/Battery_FAQ.htm

"Honda Civic Hybrid." *Wikipedia Encyclopedia*. Retrieved September 11, 2006, from http://en.wikipedia.org/wiki/Honda_Civic_Hybrid

"Hybrid Batteries Overview." *Hybrid-Cars.com* Retrieved September 11, 2005 from http://www.hybridcars.com/battery-comparison.html

"Hybrid Electric Vehicles: HEV Batteries." *US Department of Energy*. Retrieved September 11, 2006, from http://www.eere.energy.gov/cleancities/hev/hev_batteries.html

"Lead-acid batteries." *Wikipedia Encyclopedia*. Retrieved September 11, 2006, from http://en.wikipedia.org/wiki/Lead-acid_battery

"Nickel Metal Hydride Battery." *Wikipedia Encyclopedia*. Retrieved September 11, 2006, from http://en.wikipedia.org/wiki/NiMH_battery

Appendix B: An example of a schematic for the dynamometer, in this case the inverter.