MICHIGAN OHIO UNIVERSITY TRANSPORTATION CENTER

Alternate energy and system mobility to stimulate economic development.

Report No: MIOH UTC AF1, p2 2007 – Yr 1 In Process

MULTIPURPOSE EDUCATIONAL MODULES TO TEACH HYDRAULIC HYBRID VEHICLE TECHNOLOGIES

Yr 1 (multi-year) – IN PROCESS REPORT

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AF1, Series, Projects 2, September, 2007
YEAR 1 IN PROCESS REPORT

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SPONSORS

This is a Michigan Ohio University Transportation Center project supported by the U.S. Department of Transportation, the Michigan Department of Transportation (for UDM portion of the project), The University of Toledo, and the University of Detroit Mercy.

DISCLAIMERS

The Michigan-Ohio University Transportation Center has identified alternative fuels as one of the three focal areas of focus and impact. Research, technology transfer, education, and outreach to support the design and development of hybrid vehicles are among primary areas of research and education. The activities proposed in this project are directed towards the hybrid vehicles, which are closely related to the alternative fuels focus area. This project formed around an experimental setup that was developed during the first year of project at the University of Toledo. This test stand makes it possible to evaluate the performance of dual-function hydraulic mump/motors as the main components of the hydraulic hybrid vehicles. The investigating group from the University of Toledo and University of Detroit Mercy are planned to collaborate over a period of two years to develop several education modules as well as educational simulations around this test stand. To this end, experiments and simulations have been designed in the form of complete modules to teach Engineering students the fundamental concept of the hydraulic hybrid vehicle technology. These modules have elements from the core courses of the Mechanical Engineering curriculum. As such, these modules will be used to enhance the students' learning in fluid dynamics, hydraulics, energy systems, vibrations, mechatronics, and controls. The educational modules and computer simulation software developed throughout this project period will become available on the internet for other universities. Additionally, the investigators will present and publish their educational finding at the national and international conferences and in the educational journals.

Laboratory experiments:

Two laboratory experiments have been developed around the hydraulic hybrid test stands. In developing the education module for this proposal, a problem solving approach is used to improve students' learning and to ensure achieving the course objectives. A memorandum describes each of the two problems that the students must solve by performing the experiment. The memorandum is from a supervisor, who defines the purpose of the problem and defines the audience for the report. Students are not given a procedure to follow for conducting the experiment. In the lab, they will design the experimental procedure based on their engineering judgments.

In addition to the memorandums describing the problem that will be solved in the lab, background materials will be provided to the students on hydraulic components. Appendix A contains one of the laboratory experiments that were developed during year 1 of the project. Final report will contain both laboratory experiment as well as all the supporting materials.

Simulation software:

The goal of the overall project is to develop a software simulation for a hydraulic hybrid vehicle. The simulation will enable students to compare various hybrid configurations with conventional IC engine performance.

The planned activities for the project were as follows:

1. Identify and acquire software tool.
2. Perform literature search.
3. Program preliminary model for conventional IC engine drivetrain and hydraulic components.
4. Identify and hire student assistant.
5. Design user interface.
6. Refine the simulation and compare to published results.
7. Develop student materials to accompany the simulations.
8. Acquire test stand data from University of Toledo for hydraulic pump/motor efficiencies and incorporate into simulation.

Activities 1 through 6 have been completed (although refinements and comparisons are continuing); activity 7 is in progress, and activity 8 will be completed before the end of the project. A report on each of the activities is given below.

1) MATLAB/Simulink was chosen as the development tool. We considered using a lower-level language such as Visual Basic for ease of transfer among institutions and better graphics capabilities, but after discussions with co-investigators at the University of Toledo it was decided that most institutional users of the simulation would have access to MATLAB/Simulink. Programming the simulation with Simulink is also easier than using a lower level language, allowing us to concentrate on the physics. Also, it is advantageous for engineering students to gain experience with modeling in MATLAB/Simulink.

2) Many relevant references have been identified, including but not limited to:

- Gillespie, Thomas D., *Fundamentals of Vehicle Dynamics*, Society of Automotive Engineers, 1992.
- Heywood, John B., *Internal combustion Engine Fundamentals*, McGraw-Hill, 1988.
- Pourmovahed, A., Beachley, N.H., and Fronczak, F.J., "Modeling of a Hydraulic Energy Regeneration System – Part I: Analytical Treatment," *J. of Dynamic Systems, Measurement, and Control*, March 1992, vol. 114, pp. 155 – 159.
- Pourmovahed, A., Beachley, N.H., and Fronczak, F.J., "Modeling of a Hydraulic Energy Regeneration System – Part II: Experimental Program," *J. of Dynamic Systems, Measurement, and Control*, March 1992, vol. 114, pp. 160 – 165.

- Wu, B., Lin, C-C., Filipi, Z., Peng, H., and Assanis, D., Optimal Power Management for a Hydraulic Hybrid Delivery Truck, *Vehicle System Dynamics,* 2004, vol. 42, nos. 1-2, pp. 23-40.
- Lin, C-C., Filipi, Z., Wang, Y., Louca, L., Peng, H., Assanis, D., and Stein, J., "Integrated, Feed-Forward Hybrid Electric Vehicle Simulation in SIMULINK and its Use for Power Management Studies," SAE paper 2001-01-1334, Society of Automotive Engineers, 2001.
- Shayler, P.J., and Chick, J.P., "A Method of Prediciting Brake Specific Fuel Consumption Maps," SAE paper 1999-01-0556, Society of Automotive Engineers, 1999.
- Wu, P., Luo, N., and Fronczak, F.J., "Fuel Economy and Operating Characteristics of a Hydropneumatic Energy Storage Automobile," SAE paper 851678, Society of Automotive Engineers, 1985.

3) through 6) A SIMULINK model for a hydraulic hybrid vehicle has been developed. The model currently allows the user to input a drive cycle along with various vehicle characteristics, and choose among conventional IC engine, parallel hydraulic hybrid, and adiabatic or isothermal accumulator behavior. Outputs include average fuel economy, amount of fuel consumed, and energy regenerated and reused. Users can also view plots of total power, engine power, pump/motor power and other parameters such as accumulator state of charge, pressure, and temperature. Comparisons with the results from Wu et al. (2004, referenced above) are reasonable, although differences are to be expected because our model does not have the component level of detail considered by other researchers. For instance, instead of modeling the acceleration behavior of rotating parts such as the driveshaft, we use an empirical relation for an equivalent mass. To date we also consider the nitrogen in the accumulator to behave as an ideal gas. Since our simulation is intended for educational – as opposed to research – purposes, such simplifications are justified. We are currently in the process of implementing changes to account for hydraulic component inefficiencies, to allow the user to choose series or parallel hybrid configuration, and to account for nonideal gas behavior. Efforts to incorporate an accurate torque converter model have proven difficult, so the current model is for a manual transmission.

7) A document-in-progress indicating the key equations, power/braking control logic, and sample parameters has been written. The document in its final form will form a portion of the "operating manual" for the simulation.

Appendix A: Memorandum 1 for Laboratory 1

Friendly Fluid Power, Inc.
8008 L. Ron Hubbard Way
Los Angeles, CA

Dynamics and Hydraulics Laboratory,

Hydraulic Hybrid Vehicles are currently being investigated by a number of researchers and organizations in an effort to produce vehicles that are more fuel efficient and environmentally friendly. It is anticipated that a surge in demand will occur for hydraulic hybrid components as a direct result of the ensuing success of these systems. In order to be ready for this demand, Friendly Fluid Power, Inc. has developed some axial piston pump/motor units. As this is the company's first prototype design, it is desired to have a second party perform an evaluation. Consequently, we at Friendly Fluid Power, Inc. would like your research team at the University of Toledo to evaluate the performance of our units. Some general information on the pump/motors has been provided with this request. Specifically, our company would like you to develop and compare the theoretical flow rate with the actual performance as a function of the bent/axis angle and shaft speed. Please Include the following in your report:

- Describe theoretical and experimental procedures and methodologies employed.
- Describe the equipment used to acquire data including software used to model or analyze the system.
- Plot theoretical and experimental flow rate as a function of the bent/axis angle and rpm of the pump/motor.
- Discuss the difference between theory and experiment, if any, and provide possible explanations for differences. Also compare the results with the technical data provided by the manufacturer.
- Based on literature and experience, provide recommendations that could improve our design.

For additional information regarding theory and background refer to the references:

1. Skaistis, Stan. Noise Control of Hydraulic Machinery. Marcel Dekker, New York, 1988.
2. Cheremisinoff, Nicholas P. *Noise Control in Industry: A Practical Guide*. Noyes Publications, Westwood, New Jersey, USA. 1996.
3. Amin M. Motlagh, Mohammad H. Elahinia, Mohammad Abuhaiba, Walter W. Olson. Application of smart materials for noise and vibration of hydraulic systems. Accepted proceeding of IDETC2007, USA.
4. Amin M. Motlagh, Mohammad Abuhaiba, Mohammad H. Elahinia, Walter W. Olson. *Hydraulic Hybrid Vehicles*. Department of Mechanical, Industrial and Manufacturing Engineering, The University of Toledo. Toledo, Ohio 43606.
5. Akers, A., Gassman, M. P., Smith, R. J. Hydraulic Power System Analysis. Taylor & Francis Group. Boca Raton, London, New York. 2006.

Parameter	Value	Units
Fluid Viscosity		
Fluid Density		
Number of pistons	7	
Piston pitch diameter		
Piston diameter		

Data Sheet:

Test #	Shaft Speed (______)	Bent/Axis Angle (______)	Acquisition Time (______)	Parameter Mean Value (________)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
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