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Integrating Education and Research: Development of an Hydraulic Hybrid Vehicle Laboratory*

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This paper presents the development of a new hydraulic, hybrid vehicle-based laboratory course for the Mechanical, Industrial, and Manufacturing Engineering Department at the University of Toledo. The objective is to provide an educative tool for undergraduate students and to advance the research of hydraulic, hybrid vehicle technology. The educative module is based on a problem-solving learning approach that aids students in gaining a richer understanding of elements from courses of the Mechanical Engineering curriculum such as Fluid Dynamics and Hydraulics, Energy Systems, Vibrations, Mechatronics and Controls. Additionally, the modules developed for the hydraulic hybrid system will become available on the internet for other universities to utilize. The laboratory also serves as a research tool for the advancement of hydraulic hybrid vehicle technology. To this end, both graduate and undergraduate students will be performing experiments and simulations that will enhance understanding of hydraulic hybrid systems. The knowledge obtained will be utilized to help optimize the design of hydraulic hybrid vehicle technologies.

Keywords: Active learning; problem solving; hydraulic hybrid vehicles.

INTRODUCTION

HYDRAULIC HYBRID VERHICLE TECHNOLOGY is an interesting and expanding focus for researchers concerned with alternative fuels and greener solutions to emissions problems. The hydraulic hybrid concept employs many aspects of engineering fundamentals and, therefore, can provide a convenient means of integrating engineering fundamentals into an application-based learning experience. Application of hydraulic hybrid vehicle technology specifically requires knowledge of thermodynamics, fluid dynamics, kinematics, controls and vibrations and acoustics. These subjects, however, often can be very arduous for a student. This is because it is difficult to provide a solid mass of the subject, i.e. something to actually look at and study. The aim of our laboratory is to integrate a fundamental engineering curriculum in such a way as to provide a hands-on application to study the principles at work. Hydraulic hybrid vehicle technology is such an application that can be utilized to study engineering principles.

Additionally, our course will be both for undergraduates and graduates. The course will incorporate not only a hands-on problem-solving learning approach, but will also utilize and encourage basic research tools. The course is designed in such a way that students will perform a research review and assemble a paper that provides a basic survey of current research areas in the field of hydraulic hybrid vehicle technology. This way, the course provides an opportunity for undergraduate students to gain experience with basic research tools in the kind of work a graduate student is expected to perform. Also, beginning and advanced graduate students can refine and expand their experience performing research-based work. Finally, all students will have the opportunity to expand and improve upon basic and advanced communication skills via laboratory interaction and written and oral presentations of work. It is also expected that students can produce a conference publication from their work. This last point also serves as a great motivating factor in any student's desire to really master the subject matter.

PROBLEM-SOLVING LEARNING APPROACH

The effect of creative education methodologies on student learning has long been the focus of educational researchers [1]. Fink et al. [2] have emphasized the need for new methods of education in engineering. Through case studies, the authors showed the effectiveness of such methods in improving the quality of education in different

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engineering disciplines. The authors, however, justifiably count the integration of major components, such as learning tools, learning activities and learning evaluation of the course as some of the major aspects of effective learning. The authors conclude that by a proper combination of these major components, we can improve the students' willingness and ability to learn. Malicky et al. have presented a systematic approach to guide engineering educators in choosing effective pedagogy [3]. The authors recognized that both traditional and non-traditional pedagogies have advantages and disadvantages. To address this issue, the authors developed a pedagogy decision matrix to help engineering educators systematically choose the optimal method for each course. The matrix combines a scoring system with different factors about students, instructor, course, and institution that will lead to optimal decision making on the teaching methodology. The authors have used the matrix, for example, courses [3]. Faculty at Stanford University among other institutions of higher education have been using the problem-based learning approach as an effective method for teaching engineering students. As presented by Fruchter and Lewis, mentoring is an integral part of this method, which provides students with connections to communities of practice [4]. Problem, Project, Product, Process, People-Based Learning (P^5BL) is an approach that has been developed to train students in interdisciplinary team projects. Students engage in team activities to complete a project in order to practice discipline-specific knowledge in a multi-disciplinary project-centered laboratory environment, as well as to exercise newly acquired theoretical knowledge [4]. Freuler et al. have reported an effort in the College of Engineering at the Ohio State University where the freshman engineering classes were redeveloped into a combined course with hands-on laboratory elements [5]. Teamwork, project management, report writing and oral presentations were the main parts of this program. Sheppard et al. at the Carnegie Foundation for the Advancement of Teaching carried out a major study to establish the relationship between engineering teaching and practice [6]. The study emphasizes the need for effectively teaching problem solving as it is the main characteristics of engineering practice. In a recent book on the subject, John Heywood emphasizes the importance of preparing the students with the capability to identify, formulate and solve engineering problems [7].

Recently, Smith et al. focused on classroom-based pedagogy of engagement [8]. The authors recognized that active and collaborative learning provides better ways for students to learn by being intensely involved in the educational process. These learning methods can further be implemented by encouraging the students to apply their knowledge in many situations. The article, as illustrated in Figure 1, also indicates the superiority of problem-based learning over subject-based learning. The authors have identified the following attributes of the first learning method:

(1) Learning is student-centred
(2) Learning occurs in small student groups
(3) Teachers are facilitators or guides
(4) Problems are the organizing focus and stimulus for learning
(5) Problems are the vehicle for the development of critical problem-solving skills
(6) New information is acquired through self-directed learning.

More important, the problem-solving-learning approach prepares students for formulating and solving problems they have never been exposed to before. The authors have observed that the willingness and desire to learn are directly related to the ability of students to understand how knowledge can be utilized for a particular application. This last point, by default, is rehabilitated by providing the students with an applicable problem to solve.

The Mechanical Engineering Department at Virginia Polytechnic Institute and State University has been using a problem-solving learning approach to teach undergraduate students during time in laboratories [9] [10]. The laboratories integrate instruction and demonstration of engineering principles with instruction and demonstration of two-way communication. Using this approach, advanced topics have been successfully taught to undergraduate students [11]. At the Central Connecticut State University, Prusak applied the problem-solving learning approach in order to develop and improve important student skills through laboratory experiments [12]. Students were given limited guidance in developing a projectile device. The assignment aimed at giving students guided practice in engineering without clearly defined boundaries. The author reported positive outcomes in terms of inter-team communications and organization.

Morgan and Jones have studied the importance and effectiveness of computer simulations in engineering education [13]. According to this and similar studies, by using engineering software it is possible to motivate students and to stimulate learning at a number of levels. The authors further elaborated on their experience in using MATLAB® for teaching a course on control systems. They found that the use of engineering simulation software can help students with deci-

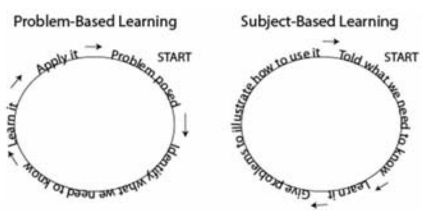

Fig. 1. Problem-solving learning contrasted with subject-based learning [8].

sion making and problem solving associated with the discipline of engineering. They also noted that students find pleasure in computer-based laboratory exercises. Many publications on engineering education emphasize the importance of teaching engineering principles using software. Pitts, using several examples, has shown the importance of basic engineering principles in each discipline [14].

Recently, Elahinia and Ciocanel employed the problem-solving learning approach to redevelop a Mechanical Engineering Laboratory [15]. They demonstrated that students respond better when the instructor serves as more of a guide rather than a figure who simply presents facts to be remembered for an exam. This learning approach encourages problem-solving brainstorming and two-way communication between small groups of students to arrive at an understanding about a given problem. The authors have further observed that the ability of students to apply knowledge in the classroom towards the solution of a real world problem is a better index of understanding of the subject matter than a simple examination based on invented problems. The ability to demonstrate an idea or principle requires a mastery of that material; therefore, the student who demonstrates an ability to use knowledge is a better index of understanding than convincing a teacher that he or she can remember what was in a textbook.

COURSE OBJECTIVES

In developing the hydraulic hybrid vehicle laboratory course, several education methods were considered in order to improve students' learning and ensure achieving the course objectives. Consequently, a problem-solving learning approach was chosen as the basis of the course. The objectives of the course include:

(1) Introduce hydraulic hybrid vehicle technology to students
(2) Enhance the students' ability to apply knowledge towards the solution of a problem
(3) Expose students to research tools and methodologies
(4) Enhance the students' ability to communicate both orally and in a written fashion
(5) Advance hydraulic hybrid vehicle technology.

This course is a 3.0 credit hour course that consists of both lecture and laboratory periods and is based on an 18 week schedule. The course will require at least one teaching assistant who will allot additional time for the students in the laboratory as well as to give advice. The course will be offered to undergraduate seniors and graduate students, for the course requires background information in Fluid Dynamics, Vibration Theory, Dynamics, Differential Equations and Linear Algebra. This course will be offered as a technical elective and will serve as a model to develop courses in other engineering disciplines based on similar principles.

COURSE OVERVIEW

In this course, learning depends upon the willingness of the student to learn. Rather than the instructor providing all the information that students will need to understand hydraulic hybrid vehicle technology via class lectures, most of the learning is done via individual study by the student. The student does this by performing a literature review of hydraulic hybrid vehicle technology and assembling a paper from it, designing experiments to solve a proposed problem concerning hydraulic hybrids, carrying out the experiments, analyzing the results of the experiments and reporting the results. Thus, by the end of the course, students have the ability to assemble all the work performed in a final report that is publication worthy. This last point serves as a motivating factor for the students to gain a mastery over the subject matter. Additionally, conclusions drawn from experiments performed will serve as a basis for improving the design of a hydraulic hybrid vehicle system.

Throughout this process, the instructor serves as a guide or manager who provides the students with advice, ideas and support. The professor will also deliver lectures on relevant material that students may require to effectively carry out their proposed solutions. Course lecture time is devoted mainly to exposing the students to research methodologies and new tools to aid investigation of engineering problems. Research techniques consist of topics such as how to perform literature queries, how to assemble a survey paper, how to submit work for publication and the importance of this, etc. Additionally, lecture time is devoted to exposing the students to software tools such as MATLAB/Simulink, AMESim, Labview, LMS Test.lab as well as introducing theory and application of transducer technologies, etc. Students are further encouraged to develop and/or introduce any desired investigative tool that may prove beneficial in solving the problem at hand. Any remaining lecture time is devoted to review of relevant material, student presentations of their progress and time spent with the instructor to discuss project progress.

Thus, step-by-step laboratory procedures are not provided to the students in this course. Instead, a practical problem is presented and the students design an experiment or experiments to investigate and/or solve it. A memorandum describes each of the problems that the students must solve by performing an experiment(s). In other words, the course is a problem-solving learning- based course to provide students with hands-on experience. This is achieved through the application of fundamental mechanical engineering principles.

Students spend two separate one-hour periods in the classroom per week and one hour in the laboratory per week. They are expected to spend additional time in the laboratory with the teaching assistant each week which is scheduled between the students and the teaching assistant. Students are encouraged to spend an additional one to two hours per week working with the hydraulic hybrid vehicle system. A tentative syllabus for the course can be seen in Appendix A.

COURSE METHODOLOGY

The first week of the course is dedicated to basic hydraulic safety precautions and an overview of how the course flows. These lectures also include a tour and demonstration of the hydraulic hybrid vehicle system. This way, the students obtain some idea of how the course will run as well as how the system works and how the system may aid the students in solving the problem of their choosing. At this time, the students ask questions and have the opportunity to use the system and become familiar with it. At the outset of the first week of class, students begin performing their literature reviews. This way, they gain hands-on knowledge of the system in the classroom in tandem with conceptual knowledge outside the classroom.

Though the students will not solve any problems in the laboratory within the first weeks of the course, they are expected to meet during laboratory periods as well as during the additional teaching assistant laboratory time to become familiar with the system. In this fashion, rather than learning how to use the system in a course, students solve a problem using the system once this has been understood. They are encouraged to spend as much time as necessary with the system to learn and understand it.

Weeks two through five are dedicated to introducing the students to some background information on hydraulic hybrid vehicles and their working principles, pump/motor dynamics, MATLAB® fundamentals, and review lectures on fluid dynamics and vibration theory. Lectures are based on a review paper that the authors have constructed. During these weeks, students will be working on literature reviews as well as carrying out some exercises in MATLAB® and solving some practice problems based on the review material. Throughout these weeks, the students will also attend laboratory sessions where they will be getting hands-on experience with the system.

At week six the individual literature reviews are completed and students are assembled into groups (two to four). They are then presented with various problems in the form of a memorandum from which the students choose, based on their literature reviews and knowledge of the test stand, which problem most interests them. Also, they may choose to originate a problem.

During weeks seven through ten, the groups combine the reviews from each member into one review paper. The group then begins reviewing specific research topics that aid in solving the problem at hand. Meanwhile, the students continue to learn about the functionality of the test rig in the lab and specifically how it can be used to aid in solving the problem. At the close of week ten, the students are expected to have a proposal written on how the group will solve the problem. Additionally, the students will prepare a proposal presentation that will be given in week 11.

The proposals will be revised as necessary based on class and instructor input and will then be carried out. Lecture time in weeks 12 through 15 will be devoted to some research methodologies based on student needs; laboratory time will be devoted to carrying out the groups' proposed solutions. By the close of week 15, students are required to write a progress report and prepare a progress presentation. The progress presentation will be given in week 16.

Final weeks of the course are devoted to finishing the experiments and analyzing the data. This entire project is wrapped up by writing a paper that includes the literature review, the problem statement, the experimental setup, the experimental procedure, the results and conclusions. Additionally, the students are asked to provide valuable feedback about the course via course evaluations as well as providing recommendations on how the hydraulic hybrid vehicle system can be optimized. A final presentation will be delivered by each team at the close of the semester.

COURSE MEMORANDUMS

A number of problems concerning aspects of the hydraulic hybrid technology have been invented and presented in memo format. In this way, a small group of students can seem to receive a request from a customer to investigate a particular problem. Based on the students' interpretations of the requirements from the customer, they propose a method of solving the problem via investigative tools made available through the laboratory. The proposed methodology is then submitted to the instructor (guide or manager), at which point he/she discusses the proposed investigation methodology and provides any necessary feedback, comments, recommendations, etc. It is then the responsibility of the students to carry out the investigation and report their procedure, observations, results and conclusions. This coupled with the previously assembled literature review serves as the basis for the students' publication submittals. Sample memorandums are presented in Appendix B, which include the following information: introduction and problem statement, customer requirements and recommendations, some references from the literature and may include additional information as needed.

Additionally, in conjunction with the Michigan-Ohio University Transportation Center, Schumack et al. have developed a simulation model of the HHV system using MATLAB/Simulink. The program is used to introduce many principles of HHV technology to the students via exercises.

Preliminary case studies with the program have been performed and positive results have been reported [16]. This model will also be utilized as a means of solving the students' engineering problems.

HYDRAULIC HYBRID TEST STAND

The hydraulic hybrid vehicle test stand simulates the operation of a series configuration type hydraulic hybrid vehicle. The system consists of an electric motor, two hydraulic pump/motor units, a hydraulic circuit and relevant transducers at key locations in the system. Figure 2 demonstrates, in schematic form, the working principles of the system.

An additional document has been prepared which details, to the students, the exact workings of the test stand. This document serves as a reference for the students as they become familiar with the system; it is in Appendix C. The document includes data sheets that can be printed out as well as an inventory of each component of the system such that the students can acquire any necessary data from the manufacturers or the operating manuals. The hydraulic hybrid test stand is shown in Figure 3 above.

Some typical functions perform by students with the experimental setup include using LABVIEW to collect pressure, temperature, vibration and noise data. Students are required to perform multiple tests at different operating conditions. Depending on which problem was chosen by the students, all or some of these tasks may be required. The data collected are then analyzed by the students in their own time at another location. They make appropriate graphs and figures to present the data in a useful form to illustrate their findings. Most of the data collected do not require signal processing, however; whether or not to process the data at this level is at the discretion of the students. This allows students to gain interactive experience with engineering tools and data manipulation processes. Students are then asked to draw conclusions from their findings and the data acquired during the experiments. Additionally, the findings are prepared in such a way as to present them to the classroom as if to a client. This also broadens the students' abilities to communicate and gain valuable feedback from peers and the instructor as to how well the problem had been solved.

ADVANCING HYDRAULIC HYBRID VEHICLE TECHNOLOGY

Advancement of hydraulic hybrid vehicle technology is achieved by the design of the course. The

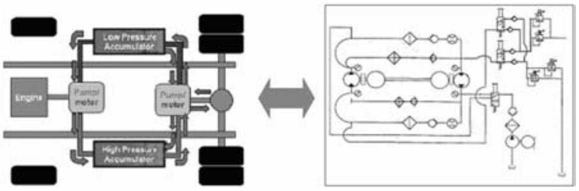

Fig. 2. Schematic of the hydraulic hybrid test stand.

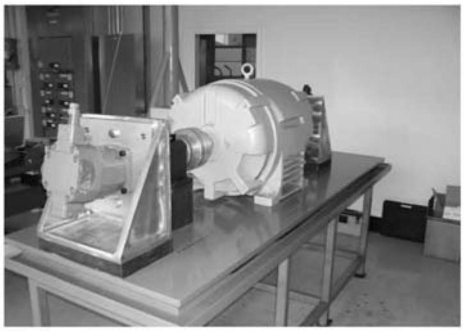

Fig. 3. Hydraulic hybrid vehicle test stand.

problem statements, contained in the memorandums, are designed such that specific areas requiring attention within the field of hydraulic hybrid vehicles are addressed. In this way, students learn HHV technology while at the same time expand current knowledge about it. The experiments, observations, conclusions and recommendations of the students will serve as a basis for continuous improvement in the design of the system. With each coming semester, the problem statements contained in the memorandums will be changed and/or altered such that new problems are addressed and students learn new aspects of the technology.

CONCLUSIONS

A novel way of introducing and advancing hydraulic hybrid vehicle technology has been proposed. The proposed approach utilizes a problem-solving learning approach that emphasizes the use of student validation and two-way communication through a hands-on application-based learning experience. The instructor serves as a guide for the students to perform and advance the research of hydraulic hybrid vehicle technologies. As an additional result, both undergraduate and graduate students gain invaluable research experience which gives them the opportunity to publish relevant conclusions.

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REFERENCES

1. D. Huntzinger, M. Hutchins, J. Gierke and J. Southerland, J. Enabling Sustainable Thinking in Undergraduate Engineering Education, *Int. J. Eng. Educ*. **23**(2), 2007, pp. 218–230.
2. L. Fink, S. Ambrose and D. Wheeler, Becoming a Professional Engineering Educator: A New Role for a New Era, *J. Eng. Educ., Amer. Soc. Eng. Educ.* **94**(1), 2005, pp. 185–194.
3. D. Malicky, S. Lord and M. Huang, A Design Methodology for Choosing an Optimal Pedagogy: the Pedagogy Decision Matrix, *Int. J. Eng. Educ*. **23**(2), 2007, pp. 325–337.
4. R. Fruchter and S. Lewis, Mentoring Models in Support of P^5BL in Architecture/Engineering/ Construction Global Teamwork, *Int. J. Eng. Educ*. **19**(5), 2003, pp. 663–671.
5. R. Freuler, A. Fentiman, J. Demel, R. Gustafson and J. Merrill, Developing and Implementing Hands-on Laboratory Exercises and Design Projects for First Year Engineering Students, *ASEE Annual Conference,* Albuquerque, New Mexico: ASEE, (2001).
6. S. Sheppard, A. Colby, K. Macatangay and W. Sullivan, What is Engineering Practice? *Int. J. Eng. Educ*. **22**(3), 2006, pp. 429–438.
7. J. Heywood, Engineering Education: *Research and Development in Curriculum and Instruction,* IEEE-Wiely, (2005).
8. K. Smith, S. Sheppard, D. Johnson and R. Johnson, Pedagogies of Engagement: Classroom-Based Practices, *J. Eng. Educ., Amer. Soc. Eng. Educ.* **94**(1), 2005, pp. 87–101.
9. M. Alley and H. Robertshaw, Interweaving Engineering and Writing: A Model Large-Laboratory Course at Virginia Tech, *ASEE Annual Conference,* Albuquerque, New Mexico: ASEE, (2001).
10. M. Alley and H. Robertshaw, An Effective Incorporation of Student Presentations Into a Large Laboratory Course, *ASEE Annual Conference,* Albuquerque: ASEE, (2001).
11. M. Elahinia, Teaching Smart Materials to Engineering Undergraduate Students: A Problem Solving Approach, *ASEE Annual Conference,* Salt Lake City, Utah: ASEE, (2004).
12. Z. Prusak, Development of Engineering Problem Solving Skills Through Laboratory Experimentation, *ASEE Annual Conference,*Albuquerque, New Mexico: ASEE, (2001).
13. R. Morgan and K. Jones, The Use of Simulation Software to Enhance Student Understanding, IEE International Symposium on Engineering Education: Innovations in Teaching, Learning and Assessment (Ref. No. 2001/046), (2001), pp. 33/1–33/6.
14. G. Pitts, How do we teach students to relate to real applications, IEE Colloquium on Engineering Education in the Twenty-First Century (Digest No: 1996/105), (1996), 5/1–5/5.
15. M. Elahinia and C. Ciocanel, Redeveloping the Mechanics and Vibration Laboratory: a Problem Solving Approach, *2006 ASEE Annual Conference,* Chicago, Illinoise: ASEE (2006).
16. M. Schumack, M. Elahinia, W. Olson, W and C. Schroeder, A Hydraulic Hybrid Vehicle Simulation Program to Enhance Understanding of Engineering Fundamentals, *ASEE Annual Conference,* Pittsburg, Pennsylvania: ASEE, (2008).

Christopher Schroeder is a second year graduate student at The University of Toledo working towards his masters degree in Mechanical Engineering. Research interests include: Experimental characterization and control of noise and vibration, alternative energy systems, smart materials and the analysis and simulation of mechanical systems.

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Mark Schumack is a Professor of Mechanical Engineering at the University of Detroit Mercy, where he teaches courses and does research in heat transfer, thermodynamics, fluid mechanics, and energy systems. Currently he is working on a solar photovoltaic demonstration project funded by the State of Michigan. He received his Bachelor's, Master's, and Ph.D. degrees in Mechanical Engineering from the University of Michigan.

APPENDIX A

SYLLABUS

Course description

This is a hands-on laboratory-based course that introduces students to hydraulic hybrid vehicle technology. It is a 3.0 credit hour course but students are expected to spend 3–6 additional hours per week on course-related material. The student is expected to have a basic understanding in the following engineering areas:

(1) Fluid Mechanics
(2) Dynamics
(3) Vibration Theory
(4) Differential Calculus
(5) Linear Algebra.

It is recommended that the student has a basic understanding of MATLAB®, but this is not essential. Students will perform basic research work including a literature review and utilize their engineering background in solving a problem using the hydraulic hybrid vehicle laboratory. Students will work in teams of 2–4; they will be expected to design and implement an experiment while documenting their procedure and results. Research work and experimental work will be integrated to produce a report that is worthy of publication. The report will be presented at the end of the course in front of the class.

Course objectives

(1) Introduce students to hydraulic hybrid vehicle technology
(2) Enhance the ability of students to apply engineering principles to solving problems
(3) Expose students to research tools and methodologies
(4) Enhance ability of students to communicate both orally and in a written fashion
(5) Advance hydraulic hybrid vehicle technology.

Recommended reading

(1) A. Akers, M. P. Gassman and R. J. Smith, *Hydraulic Power System Analysis*. Taylor & Francis Group. Boca Raton, London, New York. (2006).
(2) A. M. Motlagh, M. E. Abuhaiba, H. Mohammad W. Walter, *Hydraulic Hybrid Vehicles*, Department of Mechanical, Industrial and Manufacturing Engineering, The University of Toledo. Toledo, Ohio.
(3) S. Skaistis, *Noise Control of Hydraulic Machinery*. Marcel Dekker, New York, (1988).
(4) Supplementary information will be provided in class.

Course requirements

Students will be expected to spend a total of 10 to 12 hours per week on this course. They will be required to review relevant research done in the field of hydraulic hybrid vehicle technology each week. Additionally, they will be given assignments that will require the use of various engineering software packages, specifically MATLAB®. The students, in a group of 2–4, will be given a problem in the form of a memorandum. They will then be expected to design and implement an experiment using the hydraulic hybrid vehicle system to investigate and/or solve the problem at hand. The students will spend most of their time in the laboratory learning the working principles of the hydraulic hybrid vehicle system and implementing their experiment(s). They will also be asked to present their progress on a regular basis in a professional presentation style.

Grading

Students will be graded on their ability to communicate their work, class and homework exercises, their ability to apply engineering principles to the solution of the problem at hand, their final report and their ability to work effectively in teams.

Assessment of learning

- 5%—In and out of class exercises
- 20% —Communication skills (i.e. presentations and reports)
- 35% —Ability to design and implement an experiment towards the solution of a problem
- 10% —Group work
- 30% —Final report

Tentative class schedule/activities/list of topics covered

Week		Topic Covered	Assignment
1	Lecture 1	Class overview, hydraulic safety, tour & demo	Review 2 HHV papers
	Lecture 2	Hydraulic safety	
	Lab 1	Demonstration with TA	
2	Lecture 3	Basics of HHV technology	Review 2 HHV papers
	Lecture 4	Basics of HHV technology	
	Lab 2	Study experimental setup	
3	Lecture 5	Dynamics of pump/motor	Review 2 HHV papers
	Lecture 6	MATLAB demonstration	Simulate P/M Dynamics
	Lab 3	Study experimental setup	
4	Lecture 7	Fluid dynamics review	
	Lecture 8	Fluid dynamics review	Fluid Dynamics HW
	Lab 4	Disassemble P/M and reassemble	
5	Lecture 9	Vibration theory review	
	Lecture 10	Vibration theory review	Vibration Theory HW
	Lab 5	Study experimental setup	
6	Lecture 11	Distribute problem memos and assemble teams	Combine Lit Review
	Lecture 12	Brainstorming for experimental design	
	Lab 6	Continue study of system	
7	Lecture 13	Noise and vibration in HHVs	Review 2 relevant papers
	Lecture 14	Noise and vibration in HHVs	
	Lab 7	Continue study of system	
8	Lecture 15	Meet with Prof about ideas	Lit Review Presentation
	Lecture 16	Meet with Prof about ideas	
	Lab 8	Discuss ideas w/ TA, continue study	
9	Lecture 17	Lit Review presentations	Combine Lit Review
	Lecture 18	Lit Review Presentations	
	Lab 9	Continue Study of System	
10	Lecture 19	Proposal writing lecture	Write proposal
	Lecture 20	Presentation skills lecture	Prepare Presentation
	Lab 10	Continue study of system	
11	Lecture 21	Present proposals	
	Lecture 22	Present proposals	Proposal Revisions
	Lab 11	Implement experiment(s)	
12	Lecture 23	Research methodologies and publications	Relevant Research
	Lecture 24	Relevant topic desired by students	
	Lab 12	Implement experiment(s)	
13	Lecture 25	Meet with Prof about progress	Progress Report
	Lecture 26	Meet with Prof about progress	
	Lab 13	Implement Experiment(s)	
14	Lecture 27	Meet with Prof about progress	Progress Report
	Lecture 28	Meet with Prof about progress	
	Lab 14	Implement experiment(s)	
15	Lecture 29	Relevant topic desired by students	Progress Presentations
	Lecture 30	Relevant topic desired by students	
	Lab 15	Implement experiment(s)	
16	Lecture 31	Progress presentations	
	Lecture 32	Progress presentations	
	Lab 16	Implement experiment(s)	
17	Lecture 33	How can the system be improved?	Propose Ideas
	Lecture 34	Class evaluation	Report Writing
	Lab 17		
18	Lecture 35	Final presentations	Presentation
	Lecture 36	Final presentations	Report Due

APPENDIX B

Friendly Fluid Power, Inc.
8008 LRH 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:

1. S. Skaistis, *Noise Control of Hydraulic Machinery*. Marcel Dekker, New York, (1988).
2. N. P. Cheremisinoff, *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. A. Akers, M. P. Gassman, R. J. Smith, *Hydraulic Power System Analysis*. Taylor & Francis Group. Boca Raton, London, New York. (2006).

Friendly Fluid Power, Inc.
8008 LRH Way
Los Angeles, CA

DYNAMICS AND HYDRAULICS LABORATORY

We at Friendly Fluid Power, Inc. have successfully evaluated the performance of our bent/axis pump/motors with the help of your lab at the University of Toledo. The evaluation indicated adequate levels of performance in flow rate across the pumps at various operating conditions. Now that we are satisfied with the performance of our pump/motor units with respect to flow and efficiency, we would like to perform a noise and vibration analysis of the units. Specifically, our company would like your laboratory to establish typical noise and vibration levels exhibited by the pump/motors. Please perform the noise and vibration analyses in a series of two separate tests, respectively. Each analysis will require an individual report, one on the airborne noise and another on structural vibrations. Please include the following in your reports:

Report 1: Airborne Noise

- Describe theoretical and experimental procedures and methodologies employed.
- Describe the equipment used to acquire data and explain why this equipment was utilized.
- Identify what type of noise is emanating from the pump/motors and develop a standardized means of the most effective way for measuring and evaluating it.
- Measure and plot the level of noise in dB A of the pump/motors and compare any differences observed in "pump mode" versus "motor mode" in the frequency domain.
- Perform any additional measurements and calculations as necessary to fully characterize the noise of the pump/motor units.

- Explain how the physical phenomenon of the system corresponds to the frequency content of the noise levels.
- Provide additional information on how the noise of the system can be better evaluated and characterized, if possible.
- Based on literature and experience, provide recommendations that could provide for a quieter design.

Report 2: Structural Vibration

- Describe theoretical and experimental procedures and methodologies employed.
- Describe the equipment used to acquire data and explain why this equipment was utilized.
- Characterize the level of structural vibrations exhibited by the various components of the system (valves, pump/motors, hoses, fittings, etc).
- Plot the magnitude of the response (choose an appropriate parameter) of the various components evaluated in frequency domain.
- Identify the largest source of structural vibration and provide recommendations on how to reduce the level of vibration exhibited by this component.
- Explain how the level of structural vibration contributes to the overall noise of the system.
- Based on literature and experience, provide recommendations that could provide for an improved design with respect to structural vibrations.

For additional information regarding theory and background refer to:

1. S. Skaistis, *Noise Control of Hydraulic Machinery*. Marcel Dekker, New York, (1988).
2. N. P. Cheremisinoff, *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. A. Akers, M. P. Gassman, R. J. Smith, *Hydraulic Power System Analysis*. Taylor & Francis Group. Boca Raton, London, New York. (2006).

Power Transducing, Inc.
2210 Risk Drive
Los Angeles, CA

DYNAMICS AND HYDRAULICS LABORATORY

Our company has developed a series of hydraulic fluid power systems that utilize axial piston pump/motors. In order to better streamline our design and prototyping process, our company seeks to build a simulation model that predicts the output torque of the pump/motor units. This model will be employed to simulate the effect various port configurations have on the overall performance of the pump/motor units. To this end, we may evaluate the performance of the design before prototypes are built. We have supplied your lab with a system that we have recently designed and built. According to the geometry of the axial piston pump/motors, develop a model to predict the output torque of the pump/motor units and experimentally evaluate the simulation model.

Please include the following in your report:

- Explain how the theoretical or analytical model was developed. This model should predict the output torque of the pump/motor as a function of the pressure drop across the pump/motor.
- Experimentally evaluate the developed model by measuring and recording the output torque and pressures across the pump/motor. Do this for motor and pump modes.
- Plot the output torque as a function of the pressure drop (theoretical and experimental results) for both pump and motor mode.
- Explain the validity of the developed model based on the experimental results.
- Discuss the difference between theory and experiment, if any, and provide possible explanations for differences.

For additional information regarding theory and background refer to:

1. S. Skaistis, *Noise Control of Hydraulic Machinery*. Marcel Dekker, New York, (1988).
2. N. P. Cheremisinoff, *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. A. Akers, M. P. Gassman, R. J. Smith, *Hydraulic Power System Analysis*. Taylor & Francis Group. Boca Raton, London, New York. (2006).

Hybrid Systems Corp.
2310 Risk Drive
Los Angeles, CA

Dynamics and Hydraulics Laboratory,

Our company has developed a preliminary theoretical model of a parallel hydraulic hybrid vehicle. We would like your laboratory to evaluate our model by doing a series of studies. Each study will assume that the model has been validated. In this first study, we would like your lab to evaluate the potential fuel savings of the vehicle by testing it with different drive cycles. This is a two part study. The first part examines the performance of the vehicle under different drive cycles and the second part will consist of determining what vehicle sizes are suitable for applying this technology to.

Please include the following in your report:

- Describe the type of drive cycles that were tested with the model (whether they were obtained or developed). These drive cycles may reflect city, highway, mountainous, etc.
- Generate a plot that displays the average fuel consumption and the drive cycle for different mass vehicles.
- Determine what kind of drive cycles the vehicle exhibits the best fuel economy and explain why this is so.
- Determine the optimal size of vehicle this technology is applicable for.
- Discuss possible drawbacks from the model and provide recommendations for how it can be improved.

For additional information regarding theory and background refer to:

1. Wu, Bin, Lin, Chan-Chiao, Filipi, Zoran, Peng, Huei, Assanis, Dennis, *Optimal Power Management for a Hydraulic Hybrid Delivery Truck*. University of Michigan, Dept. Mechanical Engineering.
2. R. P. Kepner, *Hydraulic Power Assist-a Demonstration of Hydraulic Hybrid Vehicle Regenerative Braking in a Road Vehicle Application*. SAE, Inc. (2002).
3. A. Lynn, E. Smid, M. Eshraghi, N. Caldwell, D. Woody, *Modeling Hydraulic Regenerative Hybrid Vehicles Using AMESim and MATLAB/SIMULINK.*
4. P. Matheson, J. Stecki, *Development and Simulation of a Hydraulic-Hybrid Powertrain for use in Commercial Heavy Vehicles.*

APPENDIX C

HYDRAULIC HYBRID TEST RIG SPECIFICATIONS

The hydraulic hybrid test rig is designed and constructed such that it approximates the functionality of a series configured hydraulic hybrid vehicle power train. The major purposes of the test stand are to do performance testing, durability testing and educate engineers. It is designed such that the efficiency of the main components of a hydraulic hybrid vehicle can be evaluated. The purpose of this document is to serve as an introduction to the test rig as well as provide technical data for some of the components.

The basic configuration of the test rig, as shown in Figure 4, will serve as a markup to help students

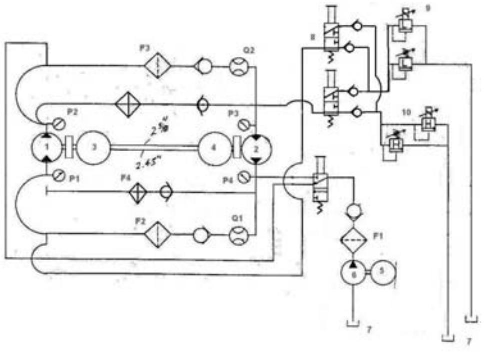

Fig. 4. Schematic of hydraulic hybrid test rig.

Table 1. Details of test stand

Detail #	Item	Spec 1	Spec 2	Spec 3	Notes
1	Pump/Motor				"Pump Mode"
2	Pump/Motor				"Motor Mode"
3	Torqe Sensor				
4	Electric Motor				See Spec Sheet
5	Electric Motor				
6	Supply Pump				Used as compensations
7	Supply Tank				
8	Control Valve				
9	Low Pressure Relieve Valves				
10	High Pressure Relief Valves				
P1	Pressure Transducer 1				
P2	Pressure Transducer 2				
P3	Pressure Transducer 3				
P4	Pressure Transducer 4				
F1	Oil Filter 1				
F2	Oil Filter 2				
F3	Oil Filter 3				
F4	Oil Filter 4				Not Currently Available
Q1	FlowMeter 1				
Q2	FlowMeter 2				

identify components and areas of interest during an experiment. It is provided on a separate sheet to allow the student to print it out and bring it to the lab. The schematic is detailed with some identification numbers for various components of the system. These details are defined in Table 1.

Also included for reference is a document that outlines and explains hydraulic schematic symbols and terminology. Refer to the document entitled 'Hydraulic Schematic Symbols' for this information. Additionally, a detailed explanation of how the test rig operates can be found in Appendix D.

APPENDIX D

HYDRAULIC PUMP/MOTOR TEST RIG OPERATION

(See Figure 4)

A motor at (1) drives a pump at (2) which draws fluid at atmospheric pressure from the supply at (3). This fluid is pressurized as it flows through the pump and goes through a directional control valve (4). The control valve can allow flow to go through line (5) or (6). Through line (5) it serves two functions: as a means of draining the line and also as a compensation to flow on the high pressure side. When directed through line (6) low pressure fluid is input to the pump/motor (serving as a pump) at (7). The pump/motor then pressurizes the fluid to a high pressure and flows along line (8) to another pump/motor at (9) and through a series of directional control valves at (10). The high pressure flow through pump/motor at (9) drives the unit in motor mode which depressurizes the flow. The low pressure fluid is then input to the pump at (7) and the cycle continues. The electric motor at (11) serves as makeup energy between the pump/motor units as there will be losses. The high pressure flow through the directional control valves at (10) is directed to a series of low and high pressure relief valves. These valves limit the maximum pressure in the system as well as serving as a means to drain the fluid back to the supply tank at (12).