Fifth LACCEI International Latin American and Caribbean Conference for Engineering and Technology (LACCEI'2007)
"Developing Entrepreneurial Engineers for the Sustainable Growth of Latin America and the Caribbean:
Education, Innovation, Technology and Practice"
29 May – 1 June 2007, Tampico, México.

Fuel Cell Mechatronics Senior Design Project

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ABSTRACT

The field of Mechatronics has grown rapidly over the last 20 years. More corporations are requiring employees who have interdisciplinary knowledge and experience in both the electrical and mechanical engineering fields. Penn State recognized the need for individuals trained in these areas and developed a 4 year Mechatronics program. This program is a Bachelors of Science degree in Electromechanical Engineering Technology (BSEMET). In the senior year of the BSEMET program, students take a senior design capstone course EMET 440. This course provides an opportunity for students to work on an interdisciplinary real-life project and gives them first-hand knowledge of project management principles. Each student team is given a budget of $1000.00 to complete the project and is required to justify expenditures. Student design teams are expected to meet with senior faculty advisors who monitor design progress and act as consultants. Having had courses covering electrical, mechanical, and computer control, students have chosen alternative energy applications such as wind energy and solar energy for their senior design capstone projects. This paper describes the success that Penn State has had in training students to complete a senior capstone project using fuel cells to run radio control model vehicles.

Keywords: Mechatronics, Alternative, Fuel Cell, Energy, capstone

INTRODUCTION - PENN STATE'S MECHATRONICS PROGRAM

PROGRAM HISTORY

Penn State has more than 100 years of history in technical training in Pennsylvania and has sought to remain up-to-date with the latest technology and programs in the fields of engineering and engineering technology. The Penn State Altoona College is one of 23 Penn State locations throughout Pennsylvania. In the early 1990's, Penn State conducted research on a Mechatronics degree program. The title given to the program was Bachelor's Degree in Electromechanical Engineering Technology (BSEMET). The title Electromechanical was used instead of Mechatronics. The term Mechatronics was more familiar in European and Asian countries but not as familiar in the US. Informal surveys were conducted by Penn State and showed strong interest from students and industry leaders. This led to a formal survey in March 1993 for the Penn State Altoona service area. The results of this survey found that an overwhelming 94% of the survey respondents projected a need for graduates of a BSEMET type program over the next five years. In addition to that, these same companies projected that 70% of existing engineering positions were suitable for BSEMET graduates.

As a result of the strong interest from current engineering technology students and an overwhelming interest from industry, Penn State Altoona implemented the Bachelor's of Science degree in Electromechanical Engineering Technology Fall 1994 with the first class beginning in fall of 1995. The first graduates of the BSEMET program began entering the work force in spring 1997.

PROGRAM GOALS

The primary aim of the Electro-Mechanical Engineering Technology program is to provide graduates with the knowledge and skills necessary to apply current methods and technology to the development, design, operation, and management of electro-mechanical systems. The program is specifically intended to prepare graduates for careers in industries where automated systems are used and to prepare them both to meet current challenges and to be capable of growing with future demands of the field. Specific educational objectives of the program are to:

- Provide graduates with a broad knowledge of electrical, electronic, mechanical, instrumentation, machine technology, computer applications, and controls applicable to electro-mechanical systems.
- Prepare graduates who can apply technical knowledge to the development, operation, control, troubleshooting, maintenance, and management of electromechanical systems.
- Prepare graduates who can communicate effectively and work collaboratively in multi-discipline teams.
- Prepare graduates who are productive professionals in technical careers and who continue to adapt to changes in the technical fields.

FACILITIES

The primary facility for students enrolled in the BSEMET program is a 15,000-square-foot engineering building that has two state-of-the-art classrooms and five engineering laboratories. In the CAD/CAE lab students are trained in the use of AutoCAD and ProEngineer. Students engage in engineering design and learn to create solid models. A Stratasys Dimension Rapid prototype machine using fuse deposit modeling (FDM) creates a three dimensional plastic part that provides real world feedback. A machine shop/chemical laboratory is used for general machining; foundry; chemical etching and printed circuit board fabrication. There is a manufacturing laboratory for robotics; programmable logic controllers; computer numerical control; CAD/CAM; flexible manufacturing systems; and computer-integrated systems. A project laboratory allows students to build projects and includes a four-ton hydraulic equipment lift; access to the exterior; space for the design and construction of student projects, and benches with variable power supplies. A controls laboratory is used to facilitate digital I/O and automatic control hardware experimentation; pneumatic/hydraulic technology; stepper/servo motor technology; and temperature, pressure, flow, and volume process control stations; Finally, a communications laboratory is used for data/information transfer and control; data communications; fiber optics; and networking.

INDUSTRY SERVED

Program graduates from the EET, MET, and BSEMET programs were surveyed in December, 1999 and January, 2000 to determine the graduates' satisfaction with their programs, employment status, job titles and responsibilities, helpfulness of their education, initial and current salaries, and further educational plans. A full report summarizing this information from graduates and employers is presented under a separate cover. This report is based on the responses of 29 alumni of BSEMET from Altoona (27) and New Kensington (2), and 10 employers (9 of Altoona graduates; 1 from New Kensington).

The major findings of the 1999-2000 survey of BSEMET graduates and employers include:

- 96.5% of respondents were employed in Engineering Technology or Engineering.
- The most common job title for initial jobs were Project Engineer (17.8%) and Engineer (17.8%) followed by Manager or Supervisor (14.3%), Designer (14.3%), and Process Engineer (14.3%). Almost half had initial salaries of $40,000 or more (48.2%).
- Manager or Supervisor (31.2%) was the most common title of current positions followed by Project Engineer (25%). The current salaries of most respondents (78%) was over $40,000.

CAPSTONE COURSE EMET 440

The electromechanical engineering technology baccalaureate program at Penn State Altoona includes a senior capstone design course, Electromechanical Engineering Technology 440 (EMET 440), currently one (spring) semester (fifteen weeks) long, earning three credits. The PSU catalog entry for the course (http://cede.psu.edu/StudentGuide) reads:

> EMET 440: Electro-Mechanical Project Design (3 credits). Planning, development, and implementation of an electro-mechanical design project which includes formal report writing, project documentation, group presentations, and project demonstrations

GOALS AND OBJECTIVES

The goal of EMET 440 is to demonstrate the ability to manage, as a team, a major project involving the planning, design, development, and implementation of a process or product. This project will be interdisciplinary including electrical, mechanical, and computer control elements. Students are required to select projects that are have strong electronics, mechanics and computers/microprocessor elements. Typical projects from past course offerings include: electromagnetically-levitated trains, obstacle-avoiding or path-following robots, a multi-legged walking robot, an electric passenger vehicle and solid fuel rocket propulsion.

CLASS STRUCTURE

The structure of the senior capstone course EMET 440 is very different from a traditional design course. The faculty supervisor for the course plays the role of an engineering manager more than a teacher addressing a class. Each student is given a budget of $1,000.00 to complete the project and is required to justify expenditures. Each week, the faculty supervisor meets individually with a student team. The goal of the meeting is to review the progress students have made over the past week in their project and to provide an opportunity for extended design review.

TEAM ENVIRONMENT

Working in a student team environment is one of the more challenging tasks the faculty advisor engages in. Teams of two students are most typical. When the teams have three or more involved often the quality of the work diminishes and it is more difficult to supervise progress of each member. The faculty advisor often discusses team related issues and acts as a mentor and coach to provide direction and guidance during points of tension between team members. The faculty advisor also monitors team activity to ensure that energetic individuals do not get carried away and do everything themselves.

ALTERNATIVE ENERGY APPLICATION – FUEL CELLS

FUEL CELL HISTORY

The fuel cell technology has gained a great deal of popular attention in the last few years as energy prices soar and the stability of our current sources of energy are increasingly in question due to global conflict. From venture capitalists to environmentalists the fuel cell is being viewed as a major component in renewable energy solutions. This is for good reason. The simplicity of fuel cell technology rivals that of its close counterpart, the battery. These two technologies share a common history and a common mechanism for converting chemical energy to electrical energy. The battery was first invented by Alessandro Volta in 1800 as a single galvanic cell complete with a cathode, anode, and an electrolyte. Batteries today share many of the same characteristics as Volta's original concept. In 1839, not too long after the battery was invented, Sir William Grove from England created the first fuel cell. Although these two technologies share a very common heritage, there are some striking differences in development and applications. The battery has enjoyed a broad, strategic place through the history of technological advances with applications in almost all sectors of our economy. The fuel cell on the other hand, has experienced a very limited slice of useful contribution to the global advancement of society. It was not until the 1950s and 1960s that the fuel cell saw its first major application in military and space applications. Fuel cells have been used in every mission to space since. Even after the successful use of fuel cells in these areas, fuel cells have not expanded beyond these areas in any material way.

In spite of the slow application of fuel cell technology, recent advances have proven this technology to be a viable contender for larger scale applications including power plants. Because of the prospects of achieving efficiencies for electric power generation of 50%–65% and minimizing or even eliminating emissions of air pollutants, fuel cell power plants offer an approach to meet the goal of reducing the negative impact of energy use within the first 2 decades of the twenty-first century. (Supramaniam, et al., 1999)

With the higher cost and questionable stability of current mainstream energy sources, this may be the historical début of fuel cell technology as a mainstream solution.

BASIC PRINCIPLE OF OPERATION

The close tie between battery and fuel cell technology has already been discussed. They are both simple devices converting chemical energy to electrical energy in multiple chemical reactions. Neither of them have moving mechanical parts. They share common elements including two electrodes, a cathode and anode, and a transfer of ions while electrons flow in a current loop through a load. The main difference between a fuel cell and a battery is, that in a battery the chemical reactants are already in the cell while in a fuel cell these reactants are supplied from outside. (Ilic*, et al. 2006) Research in fuel cell technology has produced a variety of different schemes or formulas for the chemical reactants and other major components of the fuel cell but all share the same basic operation. Using one of the most common schemes as an example, Figure one shows the basic elements of a fuel cell and the chemical reactions that lead to power generation.

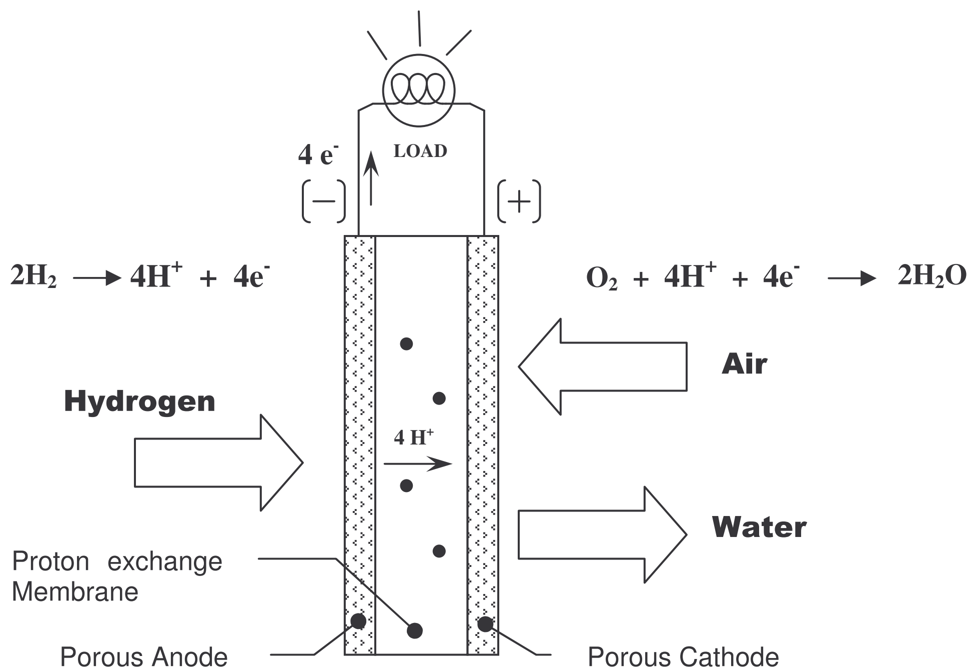

Fig. 1. Diagram of PEM Fuel Cell Operation

The fuel (Hydrogen for example) enters the fuel cell in such a way that it comes in contact with a porous anode coated with a catalyst such as platinum. There is a chemical reaction where the catalyst strips the fuel of electrons and passes the newly created ions through a material to the cathode. The electrons must take an alternate route through conducting wires, a load, then back to the cathode to be recombined with the ions. This second chemical reaction takes place in a porous material coated with a catalyst.

It is easy to see that the fuel cell represents technology that yields a continuous battery. The source of ions in a battery comes from the anode itself. When the source is depleted, the battery is dead. The source of ions in a fuel cell comes from a fuel that can be continuously introduced. The fuel cell goes dead when the fuel runs out.

TYPES OF FUEL CELLS

All fuel cells operate on the same basic principle described above. Variations in materials, fuel, operating temperatures, and power output produce the different types of fuel cells under development and in use today.

POLYMER ELECTROLYTE MEMBRANE (PEM) FUEL CELLS

Polymer Electrolyte Membrane Fuel Cells are the most commonly used fuel cell for transportation. With the cost of fuel cell components being the one of the major hindrances to fuel cell application, material selection remains as a very critical step in bringing this to the market. (Reddy, August 2006)

The Polymer Electrolyte Membrane (PEM) Fuel Cell works by means of Hydrogen getting pumped into the Stack and into each of the Maphion (a type of Graphite) cells and Platinum coated layers of film in between each cell. The Platinum layers act as a catalyst to separate the positive and negative ions of each of the Hydrogen atoms. The flow of the negative ions, or electrons, is electric current and this is where the voltage originates. The cells also known as PEMs (Polymer Electrolyte Membranes) are responsible for allowing the Hydrogen ions to bond to the Oxygen atoms that are pumped into the stack, usually via fans. This new molecule exits the Fuel Cell Stack as H2O. The best part about Fuel Cells is their byproducts. The only emissions they have are pure water and heat. Both of these can be used for other forms of energy such as heating a home or vehicle. The water can even be cycled around the Fuel Cell to cool itself. This makes Fuel Cells a highly efficient form of energy.

OTHER FUEL CELL TYPES

There are a variety of other fuel cell schemes including Direct Methanol Fuel Cells, Alkaline Fuel Cells, Phosphoric Acid Fuel Cells, Molten Carbonate Fuel Cells, Solid Oxide Fuel Cells, Regenerative Fuel Cells. Each have specific applications.

FUEL CELL PROJECT

For Spring 2006 EMET 440, a team of two senior EMET students, Ashley Ashby and Dan Mullen chose an alternative energy project involving fuel cells. The overall goal of the project was to design and build a fuel cell operated vehicle. It took some time for the students to narrow the scope and scale of the project and to become acquainted with fuel cell technology. Information was gathered from many sources including local industry, books, and journal articles from Penn State's membership in on-line databases such a Inspec and Compendex.

PROJECT REQUIREMENTS AND RESTRICTIONS

The performance goal for the project was to construct a fuel cell vehicle that met the following performance requirements.

- **Operable with the original RC components (radio/receiver).**
- **Use hydrogen as fuel.**
- **Have the vehicle run for a minimum of 5 minutes.**
- **Have computer control.**
- **Should be safe**
- **Keep the cost below budget of $1000**

DESIGN

FUEL CELL

A fuel cell was needed that would have enough power to run a Remote Controlled (RC) Car, essentially replacing the battery. The Fuel Cell that was purchased was a 20 cell stack from TDM fuel cells via eBay. The Fuel Cell was rated at 12-14 volts and 20 watts. This Fuel Cell was chosen because it had enough power to run the vehicle. The scale of this particular Fuel Cell also met the size requirements that was needed. The combination of power and size made this an ideal Fuel Cell for our project. Figure two shows the voltage fluctuation in relation to the current drawn from the cell.

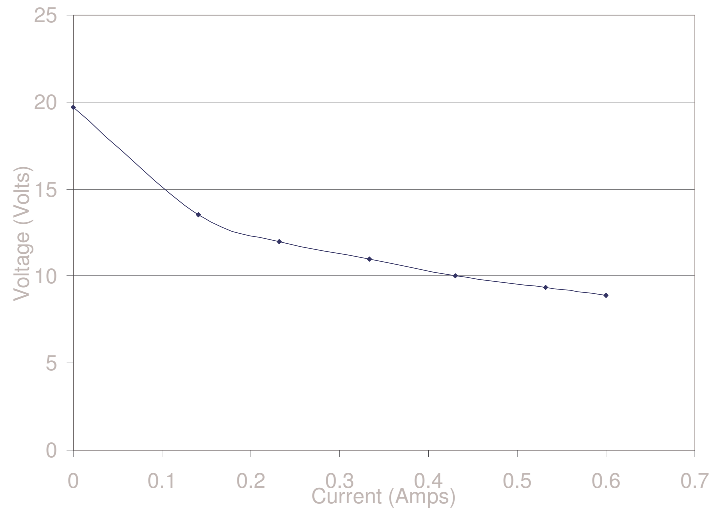

Fig. 2. Voltage vs. Current for the PSU Fuel Cell

Sample calculations for the current and resistance of the Fuel Cell are shown below.

Current: $$I = \frac{P}{V} = \frac{20}{12} = 1.667A$$

Internal Resistance: $$R = \frac{V}{I} = \frac{12V}{1.667A} = 7.2\Omega$$

FUEL SOURCE

The type of Hydrogen storage that was chosen was the Metal Hydride Cartridge (MHC). A Compressed Hydrogen Tank was considered because it was significantly cheaper than a Metal Hydride Cartridge. However, Metal Hydride Cartridges were better in every way with the exception of the price tag. They were more compact, lighter weight, easily refilled, and much safer since they were not high pressure. The maximum tank pressure for the MHC is about 180psi, while the pressure for Compressed Hydrogen ranges from 400-1000psi depending on the tank size. Another downfall of the Compressed Hydrogen Tank was that it was not refillable. This requires a new one purchased every time the hydrogen ran out. For the scale of this project, the Metal Hydride Cartridge was the better choice for Hydrogen storage. Figure three shows the difference in size between the compressed hydrogen cylinder and a Metal Hydride Cartridge.

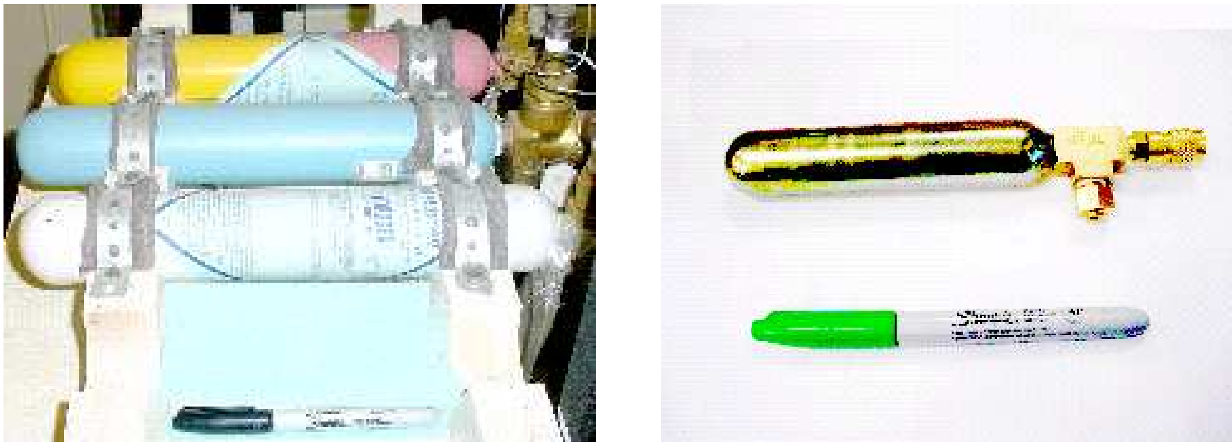

Fig. 3. Compressed Hydrogen Cylinders (Left), MHC (Right)

The consumption rate of the Hydrogen for our Fuel Cell was determined by a simple calculation. The metal hydride cartridge was quoted to hold 18 Liters of hydrogen. The consumption rate of the Fuel Cell was 0.2 Liters/minute as quoted by the manufacture (TDM Fuel Cells). To find the consumption rate the capacity was divided by the consumption rate to give a run time of 90 minutes. The calculation is shown below.

$$\text{Run Time:} \qquad \frac{18\,Liters}{0.2\,Liters\,/\,Min.} = 90\,\text{min}.$$

Since the project was on a small scale, the fittings also had to be small. Two companies were found that offered small scale fittings and valves that would meet the needs. The companies used were Swagelok and Beswick Engineering. A second consideration for the hydrogen fuel was the operating pressure. The pressure had to be reduced from the MHC storage pressure down to a pressure range of 0.5-2.0 psi. We were able to get regulators from Beswick Engineering that went that low. Our finished project can be seen in the photos below.

Fig. 4. Final Fuel Cell Vehicle

TEST AND VERIFICATION

The final Fuel Cell Vehicle is shown in Figure four. Initial tests revealed a number needed modifications. The first problem involved the MHC. The metal hydride cartridge got very cold during the tests and an external warming device was used to keep frost from developing on the outside of the cartridge.

The second problem was low power output. This problem had two major components. The first involved oxygen delivery. I improve power output, air had to be forced over the fuel cell surface. Adding muffin fans and a cowling improved the power output significantly.

A second solution to the power problem had to do with the fuel cell construction. Power output during testing was temperamental fluctuating with vehicle operation. The symptoms suggested a perforated membrane or incomplete contact within the stack. The fuel cell was later rebuilt to solve the problem.

BUDGET

.The original project allocation for the EMET 440 project was $1000. Due to the expense of fuel cells and hydrogen storage, a proposal to increase the budget was submitted. The new allocation was increased to $1500. Table one shows the major components and total project expenses.

Table 1. Fuel Cell Vehicle Budget

Item	
RC Vehicle	**$139.99**
Fuel Cell & Components	**$646.00**
Hydrogen Source & Fittings	**$573.86**
Computer Control	**$ 80.00**
Total	**$1439.85**

CONCLUSION

This paper describes activities and work related to a fuel cell senior capstone course project. There were a variety of other alternative energy application projects this semester. These include two hybrid vehicle projects, a bio-diesel project, and a small scale wind turbine project. Students are very interested in alternative energy and programs like Penn State Altoona's BSEMET program are good resources in providing the knowledge and training to meet the demands of society.

ACKNOWLEDGEMENTS

We would like to thank Mark Shuck and Bob Unger from Concurrent Technologies Corp. for the extra effort they made to help the project team understand and build the Fuel Cell vehicle. A very special thanks to Chuck Tanzola from TEM Fuel Cells for his dedication to the project and help in specifying and building a fuel cell appropriate to the EMET 440 project. Mark Hoover and Lynn Dalby from the Penn State Altoona College were instrumental in working with hydrogen storage and delivery. And John Sjolander was immensely helpful in overall design, construction, and specification of the vehicle components.

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