AC 2011-2359: ENERGY EFFICIENCY IN ENGINEERING DESIGN CURRICULUM

Alamgir A. Choudhury, Western Michigan University

Alamgir A. Choudhury is an Associate Professor of industrial and manufacturing engineering at Western Michigan University, Kalamazoo, Michigan. His MS and PhD are from NMSU (Las Cruces) and BS in mechanical engineering from BUET (Dhaka). His interest includes computer applications in curriculum, MCAE, mechanics, instrumentation & control, and fluid power. He is also a Registered Professional Engineer in the State of Ohio and affiliated with ASME, ASEE, SME and TAP.

Jorge Rodriguez, Western Michigan University

Jorge Rodriguez is an Associate Professor in the Department of Industrial and Manufacturing Engineering, and Co-Director of the Center for Integrated Design (CID) at Western Michigan University. He received his Ph.D. in Mechanical Engineering from University of Wisconsin-Madison, received an M.B.A. from Rutgers University in Piscataway, NJ., and a B.S.E. in Mechanical and Electrical Engineering from ITESM - Monterrey Campus in Monterrey, Mexico. Dr. Rodriguez teaches courses in Computer-Aided Design and Manufacturing, Mechanical Design, PDM/PLM, and Biomechanics and Finite Element Analysis. His research is in the field of computational analysis/optimization and educational computer-based tools. He has published one book on optimization, as well as more than 100 papers, with many presentations at national and international forums.

Pavel Ikonomov, Western Michigan University

Dr. Pavel Ikonomov is Associate Professor in Industrial and Manufacturing Engineering Western Michigan University He earned his bachelor degree from Technical University of Varna and his first master degree at M.E. in Mechanical Engineering and Manufacturing Technology from Technical University of Varna. His second master degree he earned from Muroran Institute of Technology, Japan and his Ph. D in Precision Manufacturing Engineering from Hokkaido University, Japan. He worked several years as chef engineer in Bulgaria, Asst. professor at Technical University of Varna. CTO at Virtual Reality Center Yokohama, Japan, Associate professor at Tokyo Metropolitan Institute of technology, Japan, Vis. Professor at UCLA and NIST. He has extensive industrial and teaching experience in different countries university research centers and companies. He is considered and expert in CAD/CAM, robotics, and Virtual Reality simulation for industry and nanomanufacturing. Dr. Ikonomov published more than 100 papers in journal, proceedings, a book and severs chapters in books, a patent.

Joseph McCoy Mydosh, Western Michigan University

Graduated in December, 2010, from the Manufacturing Engineering Technology program. Member of the the 2010 Modular Hydraulic System Test Bench senior design team.

Jason Michael Shane

Energy efficiency and sustainability in engineering design curriculum

Abstract

The knowledge and skills for the future workforce of an energy efficient industrial society are not fully nurtured in our current educational programs. Energy efficiency and innovative design practices need to be an essential part of the learning experience in undergraduate engineering design programs. Current engineering design curriculum is reformed to teach the theoretical knowledge and hands-on practices in an integrated fashion. To study energy loss and overall energy efficiency of a system and its components, laboratory practices are introduced in sophomore level thermodynamics and junior level fluid mechanics courses. A multipurpose laboratory equipped with fluid process, sensors, data acquisition system, and application programs is being developed. A series of laboratory practices based on use of fluid mechanics principles in energy efficient industrial applications provide students a strong foundation of the subject. Later in the senior level engineering design classes, these learnings are utilized to practice innovative design of energy efficient products. Industrial collaboration is established to ensure student exposure to realistic energy efficient products and practices through capstone design projects and undergraduate research.

1. Introduction

Engineering technology programs prepare students to apply their knowledge and skills in application oriented industries, as well as in research and development type of work. Energy efficiency [1], eco-friendliness and sustainability are increasingly important criteria in any industry in the increasingly competitive globalized market place [2]. The subject has received significant attention in the last decade and industries [3, 4, 5] and academia have undertaken many efforts in this area. Though the subject of energy conservation and energy efficiency is addressed in some courses, in practice energy efficiency philosophy is not the most important factor in overall design of a product or process. The issue of energy is generally one of many other design factors under the concept of cost of design and manufacturing. There is a need for deeper understanding of effect of energy efficiency on component/system design, the environment, and their long term sustainability. Therefore, current programs need to evolve by infusing these subjects in the curriculum and laboratory practices. In most engineering technology programs, the topics are introduced informally in one or more courses. Sustainability is an essential element of learning in any technical field [6,7,8], and an integrated approach to teach the concepts and practices from fundamental to advanced senior-level courses is more prudent in reforming engineering technology curricula.

This paper presents an initiative on integrated teaching of energy efficiency concepts and practices by infusing them in freshman through senior-level courses of an engineering design technology program. In contrast to other approaches, we are presenting a novel effort to expose students to sustainability through energy efficiency along with safety, environmental factors and innovation in product design in an integrated fashion. A combination of theoretical learning of the subject and experimental practices in the lab will provide students essential knowledge and skills for job readiness prior to graduation. Industry-sponsored internships and capstone design project will be an additional venue for practicing innovative and sustainable product development.

The current engineering design technology program is accredited by the Board of Accreditation for Engineering and Technology [9]. Based on the input from industry advisory board, faculty, students, alumni, and employers of program graduates, in 2009 the department initiated a curriculum reform process for all engineering and engineering technology programs. The reformed curricula are implemented starting with the Fall semester of 2010. The highlight of this reformed curricula are incorporation of energy efficiency, safety, eco-friendliness and sustainability concepts and practices in existing sophomore, junior and senior level courses. Additionally, active participation of industry is sought in the capstone design projects for innovative design of sustainable product and processes. Several industrial partners have assisted the process with fund, equipment and technical advice. This collaboration also helped develop labs for the reformed courses, and support student research and senior design projects in innovative development of fluid power applications. Recently student groups designed and developed human powered hydraulic bicycles which store rider's power during a downhill journey and propel the bike along an uphill path. Minimization of energy loss and storage of potential energy was the focal point of this sponsored design projects. Beyond classes and senior design projects, this laboratory also supports investigation on use of hydraulic energy in cost effective applications in transportation, agricultural and industrial field for both industrialized and developing regions of the world.

2. Curriculum reform

At the university level, energy efficiency and sustainability is a cornerstone of the university policy and guidelines [10]. The university promotes education, research, and innovation in energy conservation, renewable energy, environmental safety and green practices in the campus. All operational and developmental projects of the university must adapt these principles. Within the University, there are currently 27 undergraduate courses and 10 graduate level courses that address issues related to energy efficiency, renewable energy and sustainability. In the department of industrial and manufacturing engineering, the topics related to sustainability and energy efficiency is addressed in sophomore level thermodynamics and junior fluid mechanics and hydraulics courses. These courses were previously taught as two-credit-hour lecture classes with very little opportunity to address energy efficiency and sustainability. Therefore, as the department initiated its curriculum reform process, energy efficiency, sustainability and innovative product design became the main focus of engineering design technology curriculum. For comprehensive practice of the subject from freshman through senior levels, a new freshman level product design course was introduced. In the sophomore level, the thermodynamics course is reformed as a lecture and lab class, while fluid mechanics and hydraulics is transformed into a junior level lab based class. An additional senior level advanced product design course is introduced to utilize these learning in innovative product development. The main features of this reform are:

1. Theoretical learning reinforced by hands-on laboratory practices and industrial applications
2. Problem solving and case study on thermo fluid applications in industry
3. Emphasis on energy efficiency, eco-friendliness and safety in thermo fluid applications
4. Innovative design of energy efficient and sustainable products and system

Product Design Fundamentals: This is new 3 credit hour freshman level design class for the engineering design technology program to teach creativity in design through laboratory practices. Students learn to generate creative solutions of familiar problems and will design product for aesthetics, ergonomics, form, function, and utility in general. Physical models of the product are developed to demonstrate utility of the designed product. Elementary engineering analysis for detail design based on a conceived idea is introduced. It will allow nurturing creativity in design early and prepare students for innovative product design in the senior level. The reformed courses are:

Thermodynamics: Previously this was a two-credit hour lecture-only course without laboratory practices. The curriculum is reformed as a lecture and lab-based course. Beyond basic thermodynamic principles, energy efficiency of different thermodynamic cycles, factors contributing to losses in energy conversion systems, such as, internal combustion engines, turbines, power plants, refrigeration, and heating and cooling systems is discussed in more detail. Energy loss in thermodynamic processes, its macroeconomic and environmental perspective is explored. The nature and extent of current fossil fuel based energy sources; their alternative in solar, wind, geothermal, and other renewable forms is also introduced. In the laboratory, students learn the nature and sources of energy loss, practices to minimize energy loss, recover lost energy and enhance energy efficiency of thermal and fluid powered systems. Students go through detailed problem solving sessions to understand thermodynamic applications and their underlying theoretical basis.

Fluid Mechanics and Hydraulics: This course was a sophomore level two credit hour theory class. The course is reformed as a junior level three credit hour lecture and lab based course. Besides fluid statics and fluid dynamics theory, laboratory practices involving sources and nature of energy loss in a fluid power system and its components, and the design of a system for energy efficiency and safety are explored. The laboratory practices also expose student to sensors, data acquisition, and instrumentation technology practices in modern industrial applications. The goal is to apply the knowledge gained in the thermodynamics and fluid mechanics classes in design of innovative energy efficient and sustainable systems in a senior level course.

Advanced Product and System Design: This new senior-level course is developed to broaden the scope of product and system design encompassing energy efficiency and safety in innovative and sustainable products. Specific topics covered are, design for assembly/ manufacturing, design for sustainability, and failure mode and effect analysis. Computer aided engineering tools for concept generation, evaluation, and integrated design of components/systems is utilized in the lab. Lab practices are a dual track of projects; one with 1-2 week projects covering the new topics and knowledge delivered in the lecture, and the other track is two 6-week projects where concept integration is practiced. Most projects will have sustainability concepts included in them, with one of the larger projects requiring the application of energy efficiency in hydraulic/thermal systems.

Senior Design Project and Student Research: Prior to graduation, seniors of the program are required to complete a senior design project - design and development of a product or process in a two-semester time frame. The projects are either industry sponsored or based on faculty research. During the two semesters, each student group start with the design problem, brainstorm concepts, go through the detail design process to document the complete design specification, develop the designed system or a working prototype, prepare a design report, and finally present the design project in an open public forum. Because of this curriculum reform, in future senior design projects students will have the opportunity for innovative design of energy efficient and sustainable products.

3. Laboratory development

Existing fluid power laboratory with electro-hydraulic trainers is expanded to include additional temperature, heat transfer and fluid flow system. The temperature system consists of a low pressure water flow system with an electric heater and water cooled heat exchanger. The temperature of water can be controlled manually by manipulating the flow, heating, and cooling parameters. Students of the thermodynamics class use this system for temperature and energy measurement, and energy balance of a thermodynamic system. The heat transfer device is an insulated heating and cooling column connected by a cylindrical body. By measuring heating/cooling rates, dimensions and temperature at two ends of the body, students can study heat transfer characteristics and thermal conductivity of various materials. The fluid flow module is a system with four modules – power module, flow module, loading module and conditioning module (Figure 1). These modules are equipped with quick connect couplings to assemble a system as necessary in a lab exercise or research applications. The objective is to let the student experience processes from a simple fundamental one to progressively complex industry-like process in the same laboratory. The power module has an adaptable pump mount to study characteristics of different types of pumps. The pumps are driven by a generic electric motor with universal coupling and control for speed, torque and power. The fluid reservoir and filtration system is also part of this module. The flow module is used to study energy loss in a flow system composed of pipes, tubes, bends, elbows and hydraulic valves. Using flexible quick connect fittings, these components can be assembled to produce a variety of flow circuits. The loading module uses a hydraulic motor/cylinder to produce a desired speed and force/torque. An electrical generator or a gravity loading device allows application of a desired load on the hydraulic motor/cylinder. The conditioning module is shell and tube heat exchanger and brings fluid temperature to a desired level before returning to the reservoir.

To monitor the process variables such as pressure, temperature, force/torque, flow rate, position and velocity; a variety of sensors, transducers, and measuring instruments are utilized. Using National Instrument's PXI/SCXI data acquisition hardware, students can monitor and record the measured data and utilize them to control the system. For an in-depth experience in process monitoring, data acquisition, data processing, and design and development of an application, integration of NI hardware and the LabVIEW software with the hydraulic and thermal system is extremely valuable.

The University has a site license for a variety of software packages including IDEAS, ProE, Labview, ADAMS, Automation Studio and Matlab Simulink. Therefore, students of senior design projects are able to analyze the behavior of a system and simulate the performance of a design prior to actual development. Compared to an integrated overall system from a specific vendor, use of components of different origins allows students to understand the problems associated with a system development in real life and learn the technology in more detail. As opposed to a turnkey project, this approach is also a cost effective method for creating such a facility. The schematic of the overall laboratory setup is shown in Figure 2.

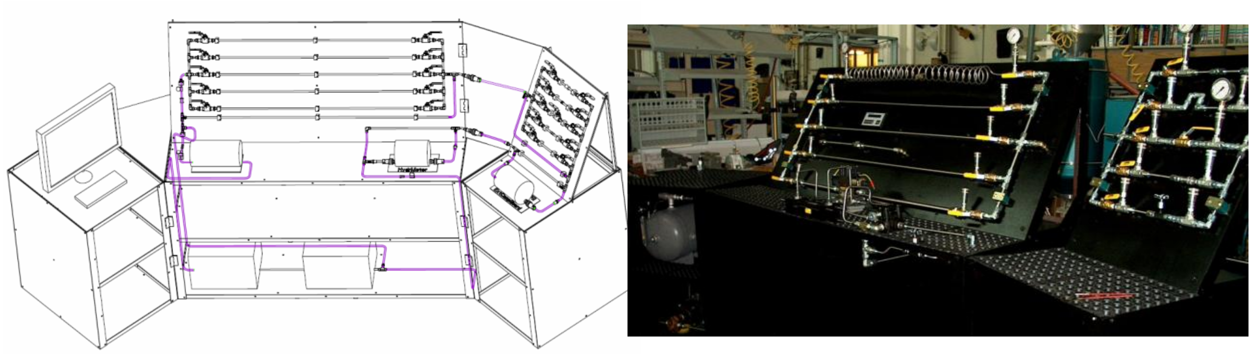

Figure 1
Modular hydraulic test bench development process

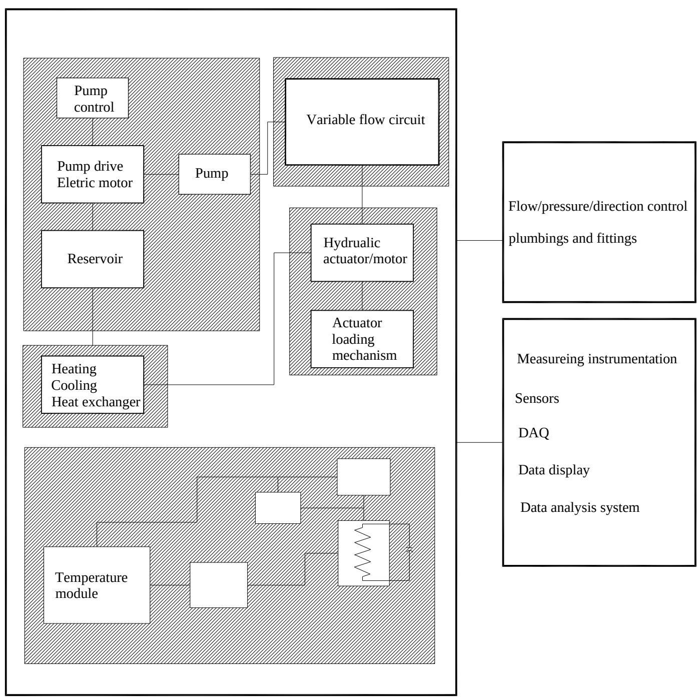

Figure 2
Layout of thermo-fluid process laboratory

4. Laboratory experiments and problem solving tools

Thermodynamics: Besides routine lecture class, both laboratory experiments and problem solving sessions are introduced in this class. For clarity, some of the typical lab experiments are listed below.

1. Calibration of instrument and measurement of temperature in a water flow process
2. Energy balance in a thermal flow system
3. Heat transfer and thermal conductivity of engineering materials.

Problem solving sessions lead students to analyze a thermodynamic system and solve efficiency, thermal energy and work output problems. Comparative performance of different thermodynamic cycles, effectiveness of energy recovery system, and performance of thermal power plants is studied though problem solving. In these session students also use computer program to investigate performance of a thermodynamics system under different operating conditions.

Fluid mechanics and hydraulics: Among ten laboratory exercises scheduled in a semester, the new laboratory setup will allow practice of seven of them. Remaining practices utilize existing motion and control laboratory. These new exercises are:

1. Measurement of fluid flow parameters
2. Development of a fluid power system for rotary power application
3. Investigation of fluid friction principles
4. Friction loss in hydraulic system components
5. Efficiency characteristics of positive displacement pump
6. Characteristics of linear actuators
7. Safety circuit for fluid power applications

In the lecture class, case studies of innovative applications to improve energy efficiency and sustainability in the industry are presented.

This reform of the curriculum is implemented from the Fall semester of 2010. Course evaluation data of the fall semester shows significant improvement in student satisfaction in all areas compared to Spring 2010 semester. Analysis of student learning outcome data will continue over the coming years and used for further improving the curriculum and related pedagogical tools.

5. Conclusion

Undergraduate curriculum of engineering design technology program is reformed for incorporating energy efficiency and sustainability in product design practices. The reformed curriculum will engage students in this subject from freshman through senior years and allow them to utilize this learning in innovative design of energy efficient and sustainable products for local and global market.

6. Bibliography

1. McLean-Conner, P., Energy Efficiency: Principles and Practices, 1st edition, PennWell Corp., 2009.
2. Graedel, T. E. and Allenby, B. R., Industrial Ecology and Sustainable Engineering, Prentice Hall, Boston, MA, 1st edition, 2010.
3. Dow Chemical Company, www.dow.com
4. Johnson Controls Incorporated, http://www.johnsoncontrols.com/publish/us/en/products/building_efficiency/energy_efficiency.html
5. Lueking, A. L., Ross, D. A. and Weber, W. J., "Environmental Sustainability Education at the University of Michigan: Collaboration with Industry to Provide Experiential Learning Opportunities", Proceedings of the 2003 ASEE Annual Conference & Exposition, paper AC2003-156.
6. Bhamra, T. and Lofthouse, V., Design for Sustainability, 1st edition, Ashgate Publishers, Inc., 2007.
7. Grasso, D., "Engineering, the Environment and Sustainability - Mind Expanding and Necessary", Proceedings of the 2003 ASEE Annual Conference and Exposition, paper AC2003-251.
8. Rosentrater, K., and Kongar, E., "Not Just Informative, But Necessary: Infusing Green and Sustainable Topics Into Engineering and Technology Curricula", Proceedings of the 2008 ASEE Annual Conference & Exposition, paper AC2008-574.
9. www.abet.org
10. http://www.wmich.edu/sustainability/about/index.html