



Case Study: Industry-sponsored Mechanical Engineering Capstone Senior Design Projects

Dr. Hosni I. Abu-Mulaweh, Purdue University, Fort Wayne

Hosni I. Abu-Mulaweh received his BS, MS, and PhD degrees in mechanical engineering from the Missouri-University of Science and Technology in 1984, 1987, and 1992, respectively. Currently, he is a professor of mechanical engineering at Purdue University Fort Wayne. He is also the mechanical engineering capstone senior design coordinator. His research interests include heat transfer, thermodynamics, and fluid mechanics.

Nusaybah Abu-Mulaweh, Purdue University, West Lafayette

Nusaybah Abu-Mulaweh is a Continuing Lecturer in the Engineering Projects In Community Service (EPICS) Program at Purdue University in West Lafayette, Indiana. She received her Bachelors of Science in Computer Engineering from Purdue University Fort Wayne, and received her Master of Science in Electrical and Computer Engineering from Purdue University in West Lafayette, Indiana. She is currently pursuing her PhD in Engineering Education at Purdue University in West Lafayette, Indiana.

Case Study: Industry Sponsored Mechanical Engineering Capstone Senior Design Program

Abstract

In our mechanical engineering program, capstone senior design projects are accomplished during an undergraduate's senior year and spans two semesters. In the first semester, the problem statement is formulated and the basic conceptual designs are generated and evaluated. The conceptual design that solves the problem best is then selected and a complete and detailed design is generated by the end of the first semester. In the second semester, a prototype of the finished design is built, tested and evaluated.

The aim of this paper is to present how industry partnerships have been developed, discuss the degree of involvement of the industry sponsors and their role during the course of the design project, and brief description of the industry sponsored design projects that were completed in the 2016/2017 academic year.

Introduction

The cost of constructing a prototype of a finished design is usually high. This is especially true when design projects deal with solving practical and real-world engineering design problems [1]. For small undergraduate mechanical engineering programs, such as ours, resources are limited. Therefore, funding the construction of these high cost designs tends to cause problems and hinders the selection of good quality capstone senior design projects. This problem becomes more pressing when the senior design projects are multidisciplinary which require higher budget. Multidisciplinary projects are needed in order comply with the Accreditation Board for Engineering and Technology (ABET) accreditation criteria [2], which require that graduates of engineering programs possess an ability to function on multi-disciplinary teams. To overcome this problem with funding, our mechanical engineering program has established strong partnerships with the local industry organizations. . Over the years, the partnerships have proven to be beneficial to both parties involved. While, industry partners provide real-world projects, sponsor these projects, and get access to students who find solutions to these problems, our students get real-world experience by working on real projects for the capstone projects.

The Partnership

The city of Fort Wayne is located in the heavily industrialized area of north eastern Indiana. Examples of some of the industry located in this area are General Motors Fort Wayne Assembly Plant, Zimmer Biomet, Fort Wayne Metals, PHD, Inc., Franklin Electric, WarerFurnace International, Inc., and a large number of small engineering and manufacturing companies. Because of this, our mechanical engineering program began seeking the involvement of these

local industries.. This was accomplished by writing to these industries in the area and by making plant visits to discuss the possibility of having the company supply and sponsor a project for a problem that needs solving. A good percentage of our own mechanical engineering students work at these companies, either as a full-time, part-time or co-op. Therefore, it was a great benefit to have students who could reach out to their employers and encourage them to supply and sponsor projects. Moreover, the Industrial Advisory Board (IAB) of our mechanical engineering program is very supportive of our program, especially our capstone senior design program. They have provided us with many senior design projects over the years.

The reception of this idea by local industry was very positive because they realized they would benefit greatly. Industry organizations get their design problems solved free of labor costs; all they would need to pay for are the parts and materials. Additionally, this provides the mechanical engineering program with support for practical and real-world engineering design problems.

The types of design projects that local industry organizations are interested in include the following:

- Developing a completely new design to perform specific task(s);
- Modifying or improving an existing design;
- Solving problems with their current industrial operations.

Each senior design team is advised by a faculty member and a company representative (advisor) who is usually an engineer or a manager at the company.

This approach proved to be highly successful. This is evident from the fact that: 1) after their first experience with our program, the companies come back and propose/sponsor more projects, 2) in the last decade and a half, the vast majority of capstone senior design projects are now sponsored by local and regional industry. In fact, in the 2016/2017 academic year, all seven projects were proposed and sponsored by local industry organizations. This approach also improved the quality of the projects. With the help of industry, these capstone projects are now very practical and solve real-world design problems. In fact, ABET reviewers deemed these projects to be of high quality and commended the mechanical engineering program for these outstanding design projects.

The Design Process

For the capstone senior design, students follow the design process the one outlined by Bejan et al [3] and Jaluria [4]. The first essential and basic feature of this process is the formulation of the problem statement. The formulation of the design problem statement involves determining the requirements and specifications of the system, the given parameters, the design variables, any limitations or constraints and any additional considerations arising from safety, financial, environmental or other concerns. The second step in the design process is the configuration and main features of the system are given in general terms to indicate how the requirements and constraints of the given parameters will be achieved. The conceptual design may range from a new idea to available concepts applied to similar problems and modifications in existing systems.

The selected conceptual design leads to an initial design that is specified in terms of the configuration of the system, the given quantities from the problem statement and an appropriate selection of the design variables.

Next is modelling and simulating the system. Modelling involves simplifying and approximating the given system to allow a mathematical or numerical solution to be obtained. Material property data, experimental results and information on the characteristics of various devices are also incorporated in the overall model to obtain realistic results from the simulation. The results from the simulation are used to determine if the design satisfies the requirements and constraints of the given problem.

The mechanical engineering capstone senior design program emphasizes several important skills that are necessary to be a successful engineer. Some of these skills include project planning and scheduling, creativity and concept generation and evaluation, decision making, analysis tools, prototyping and testing, standards and regulations, engineering ethics, oral and written communication, and team work,.

Industrial Sponsor's Contribution

In most cases, in addition to sponsoring the design project financially, the industrial sponsor is involved with the design project from the start to the end. This is because they are interested in the outcome of the project. The industrial-sponsor's contribution can be summarized as follows:

- **Project Proposal:** They provide a brief description of the problem they want a senior design team to work on. The description includes the main requirements and specifications that the design must achieve along with the available budget.
- Once the senior design team is formed, a meeting is arranged between the sponsor and the design team along with their faculty advisor. Usually this meeting takes place at the company. In this meeting, the design team discusses the details of the project with the company representative who will be involved in consulting and advising of design project throughout the duration of the project which is two semesters.
- There are several milestones for the design project (formulation of the problem statement, concept generation, concept assessment and evaluation, and detailed design). The design team seeks input and feedback from the sponsor at the end of each milestone.
- **Participation in the Design Reviews:** There are three design reviews in the first semester and one in the second semester. These reviews are carried out in the form of oral presentations. The industrial-sponsor attends these reviews and participate in the evaluation. The design reviews are structured as follows:

First Semester

- System Requirements Review (SRR): Completeness and suitability of the problem statement and resulting set of requirements which quantify the problem definition is assessed.
- Preliminary Design Review (PDR): Assessment the selected conceptual design to confirm that the design approach satisfies the requirements, risks are under control and that the preliminary design is ready to be detailed.
- Critical Design Review (CDR): A formal end-of-semester oral presentation of the detailed design.

Second Semester

- System Verification Review (SVR): A formal end-of-semester where the students present the results of their semester work to faculty and sponsors that demonstrate that their prototype meets the needs of the problem statement and satisfies the requirements.
- Most projects are built and tested at the company's site. Company technicians help in the building of the prototype.
- Course Outcomes Assessment: When the project is completed at the end of the second semester, the industrial-sponsor is asked to assess the course outcomes. This is done via an assessment form that the sponsor completes. Feedback from the sponsors indicates that they are satisfied with the results and the vast majority of them come back and sponsor more projects.

Capstone Senior Design Projects Completed During 2016/2017

Seven capstone senior design projects were successfully completed during 2016/2017 academic year. All seven projects were industry sponsored. Four projects were multidisciplinary which involved mechanical and electrical/computer engineering students. These projects were advised by two faculty members: one mechanical and one electrical/computer engineering faculty. The other three projects were single discipline (i.e., mechanical engineering projects).

Multidisciplinary Projects:

1. Project Title: Force Sensor for "Grippers"
Design Team: 2 ME & 3 ECE
Sponsor: PHD, Inc.

PHD, Inc. requires assistance in designing a sensor that can be placed in a gripper jaw to measure applied gripping force during operation. When the sensor is applied, the measurement will be utilized by the customer's programmable logic controller (PLC).

PHD, Inc. would like the sensor design to be scalable to fit the GRH, GRK, and GRR families of grippers. The range of measured force is between 12 and 800 pounds. The sensor must be scalable to accommodate varying gripper sizes and forces, and should also be calibratable for the weight of the customer's tooling. The accuracy of the measurement must be within 5% of the applied force. The mechanical interface and electrical force sensing system must withstand or be easily serviceable to withstand 10 million gripping cycles without mechanical fatigue-failure, and measurement degradation.

2. Project Title: Prototype Cell Wash Base Unit

Design Team: 2 ME & 3 ECE

Sponsor: Zimmer Biomet

Currently, the red blood cell rejuvenation and wash devices are stationary and are often located in a blood bank or in the operation room. Oftentimes, each step of the blood wash process is performed by a different device, which adds time. A need has been recognized by Zimmer Biomet for a more efficient, portable, and faster system. Zimmer Biomet has requested a senior design project to create a cell wash base unit. The design is intended to reduce the waste caused by disposable components used in the typical blood transfusion process. The objective for the design team will be to create the drive and control systems for the existing rotor design. The device must be able to drive a rotor through electrical circuits generating magnetic force. Additionally, the device must be able to be fixed to a cart and rolled in the OR, ICU, or patient floor. The design will include the electronic circuitry, electronic feedback, mechanical components, and stability of the rotor.

3. Project Title: Rolling Drum

Design Team: 3 ME & 3 ECE

Sponsor: Custom Engineered Wheels, LLC

Rolling Drum systems are used to test the durability of manufactured wheels and to determine the lifecycles of manufactured wheels. Through the use of rolling drum wheel testers Custom Engineered Wheels, LLC (CEW) is able to provide better engineered products and solutions for their customers with objective data. The task is to develop and build a new dynamic rolling drum that will replace and update the current system used at CEW. The device must be capable of simultaneously testing multiple wheels under various loads up to 400 lbs. The newly designed fixture arms will be used to test wheels above a rolling drum which may or may not have cleats attached. The fixture arm also allows for weights to be placed above the wheels in order to apply various loads. The interface to control the system will also be updated to include the interface which is already used throughout the production facility.

4. Project Title: Automated Frame Spacer/Pin Removal
Design Team: 3 ME & 3 ECE
Sponsor: General Motors Fort Wayne Assembly

General Motors Fort Wayne Assembly is a light duty truck assembly plant which manufactures ½ ton - 1 ton trucks at a rate of about one truck per minute. Frame spacers are installed between the chassis to allow the chassis to be transported in a stacked configuration and protect the frames during movement. The current manufacturing process begins as these frames are removed from the rail car. These stacked chassis are then separated and introduced into the assembly line using an incoming buffer conveyor. It is at this point where four frame spacers are removed manually by an employee, who is working independently in an isolated area. General Motors is looking to develop an automated concept-of-design prototype of this current process. The process will require the system to find the spacers, operate the spacer removal mechanism, and transport the spacers to a collection system. If the system fails to remove a spacer, an alert must be sent to an operator for manual spacer removal.

Mechanical Engineering Projects

1. Project Title: Inline wire Pre-Coater
Design Team: 3 ME
Sponsor: Fort Wayne Metals

This project includes the designing, building, and testing of a new Inline Wire Pre-Coater for the wire drawing process. The Inline Wire Pre-Coater's function is to act as a means of placing pre-coat on wire along with drying the pre-coat before the drawing process. This new inline pre-coater will include a tank for storing and heating the pre-coat solution, a means of moving the pre-coat into the coating areas, and will also include a drying section to solidify the pre-coat onto the wire surface. The new design will also need to incorporate a smaller footprint than commercially available units and will need to accommodate a variety of wire sizes and a range of drawing speeds.

2. Project Title: Rotary Actuator Damper
Design Team: 3 ME
Sponsor: PHD, Inc.

Some of PHD, Inc. highest selling products are in the family of pneumatic rotary actuators. Currently, one of the restrictions that limits the customer's application is the kinetic energy constraint. Often, the rotary actuators exceed the kinetic energy limits due to the excessive inertia from various applications. PHD, Inc. to design an external attachment to increase the kinetic energy constraint on the family of rotary actuator

products. The goal of this project is to design a scalable, cost-effective, accessory system that will increase the kinetic energy limits of the rotary actuator family.

3. Project Title: Bocal Hardness and Curvature

Design Team: 3 ME

Sponsor: Fox Products Corporation

Fox Products of South Whitley, Indiana is a manufacturer of double reed musical instruments. These include bassoons, contrabassoons, oboes and English horns. Fox seeks to improve uniformity in the hardness of their bassoon bocals. A bocal is a hollow conical metal tube attached at the small end of a musical instrument to extend its length. For the scope of this project it is made of silver plated nickel silver. In addition to uniform hardness, the bocal bending process should also yield consistent curvature and consistent length. Fox Products has determined a uniform hardness and consistent curvature will enhance the bocal's acoustical properties. The successful completion of this project will require a bassoon bocal with an average hardness of HRB 42-45. The most current average hardness is HRB 70. The current standard deviation of 8.5 should also be reduced by at least 20%. The final dimensions of the bocal must match Fox Products' current design with a +/- 0.010" tolerance.

Conclusion

This article has shown that establishing a partnership with industry is crucial in having a successful capstone senior design program. The industry-sponsored projects give our senior students the opportunity be exposed to quality, practical and real-world design problems. This kind of experience prepares our graduates well and helps them in getting jobs with those sponsoring industries. Moreover, the paper discussed how the relation/partnership between our mechanical engineering program and the local and regional industry was developed and the degree of involvement of the industry-sponsors and their role during the course of the design project, which could be helpful for other engineering programs. A brief description of the industry-sponsored design projects that were successfully completed in the 2016/2017 academic year.

References

[1] R.M. Counce, J.M. Holmes, and R.A. Reimer, "An honors capstone design experience utilizing authentic industrial projects," *International Journal of Engineering Education*, Vol. 17, pp. 396-399, 2001.

[2] ABET Engineering Accreditation Criteria, Criterion 3: Program Outcomes and Assessment, <http://www.abet.org>, 2016.

[3] A. Bejan, G. Tsatsaronis, and M. Moran, *Thermal Design and Optimization*, New York: John Wiley & Sons, 1996.

[4] Y. Jaluria, *Design and Optimization of Thermal Systems*, New York: McGraw-Hill, 1998.