AC 2008-1617: CENTRIFUGAL PUMP TEST BED: A SENIOR CAPSTONE PROJECT

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Centrifugal Pump Test Bed: A Senior Capstone Project

Abstract
A centrifugal pump test bed was designed, built and tested for the undergraduate mechanical engineering thermal fluids laboratory at Western Kentucky University. This project was funded through the Undergraduate Senior Project Grant Program sponsored by the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. (ASHRAE) and is primarily intended for instructional situations.

The project was executed over a two-semester Mechanical Engineering Senior Project design sequence, with a three-member student team planning the project design during the fall semester and executing the project construction and testing during the spring.

The final system delivered uses two 1.0 horsepower pumps that can generate a range of volumetric flows and a piping system capable of varied impedances and flow paths. A useful innovation by the team was the capability of modifying pump impeller diameter, as well as flow paths. Existing hands-on laboratory courses now have a centrifugal pump test bed to demonstrate the full complement of pump similitude: series and parallel configurations, rotational speed effects, and varied impeller size.

During the senior design course sequence, the students generated a design and selected critical components in the pump demonstration bed to provide the desired capabilities, executed the project construction demonstrating their ability to work together as a team, managed the project and maintained a schedule within time and fiscal budgetary constraints, and finally implemented appropriate testing of the final system through an experimental test plan to assure that the desired quality was achieved. This paper will detail project outcomes and faculty observations of the process and assessment of student work.

Introduction
Every year the American Society of Heating, Refrigeration, and Air Conditioning (ASHRAE) funds the Undergraduate Senior Project Grant Program, which awards schools grants for the execution of senior projects. The grants are often used to design, construct and test projects. The distribution of these funds is based on the relevance of the proposal to educational endeavors in the Heating, Ventilation, Air Conditioning and Refrigeration (HVAC&R) disciplines. [1, 2, 3]

In 2005, ME seniors and their faculty advisor in the ME Senior Lab I course at Western Kentucky University submitted a proposal to the ASHRAE Undergraduate Senior Project Grant Program, requesting funds to design, build and test (DBT) a Centrifugal Pump Demonstration System. The proposal was selected by ASHRAE as one of the projects to be funded for the 2006 – 2007 academic year.

The stated scope of the project was to design, build and test (DBT) an educational demonstration or instructional unit to allow undergraduate students to evaluate the behavior of centrifugal pumps in a variety of operating conditions. The unit was to be used to complement an engineering science course in fluid mechanics by providing mechanical engineering students with hands on experience in the characterization of pump performance. This included series and parallel operation with multiple pumps, and pump performance with various impeller sizes and rotational speeds. Pump efficiencies were also to be directly measured. All pump performance experimental data was to be conveniently compared to manufacturer's pump performance data and to theoretical predictions. This work was performed by a group of seniors in ME 400 - ME 412 at Western Kentucky University, designated CentriPump. The project was completed in June 2007 and was turned over to the Department of Engineering.

Theoretical Background

Centrifugal Pumps are turbomachines, which convert mechanical energy into hydraulic energy by imposing a centripetal force on the liquid. In a centrifugal pump, the mechanical energy of the liquid is increased by this centripetal force or centrifugal action. The liquid enters through a suction connection concentric with the axis of an impeller. The impeller is a high-speed rotary element with radial vanes integrally cast into it. Liquid flows outward in the spaces between the vanes and leaves the impeller at a considerably greater velocity than at the entrance to the impeller.

The liquid leaving the outer periphery of the pump is collected in a spiral casing called a volute. It then leaves the pump through a tangential discharge connection. In the volute, the velocity head of the liquid from the impeller is converted into pressure head. Since the mechanical energy is converted into a pressure head by centripetal force, the pump is classified as centrifugal. Input energy or power is applied to the fluid through the impeller. The impeller is directly connected through a drive shaft to an electric motor.

Centrifugal pumps are found in virtually every industry. After motors, centrifugal pumps are arguably the most common machine, and they are a significant user of energy. Given design margins in the systems incorporated, it is not unusual for a pump to be found to be over-sized or poorly selected for its intended duty. The results of poorly sizing a centrifugal pump for a particular application can be either catastrophic or simply costly due to pump inefficiencies when operated outside of its intended operating range. Therefore, undergraduate mechanical engineers should be well trained in this design or selection process through analytical and experimental methods learned in engineering science and experimental course work, respectively.

In this light, to gain an understanding of the operation of the centrifugal pump[4], first consider the energy transfer of a pump by applying the steady state form of the energy equation as follows:

$$\dot{Q} + \dot{W}_s = \dot{m}_{outlet}\left[h + \frac{V^2}{2} + gz\right]_{outlet} - \dot{m}_{inlet}\left[h + \frac{V^2}{2} + gz\right]_{inlet} \tag{1}$$

By definition the enthalpy, h, in Equation (1) is

$$h = u + Pv = u + \frac{P}{\rho} \tag{2}$$

and by conservation of mass for the axially inlet and tangential outlet of the centrifugal pump:

$$\dot{m}_{outlet} = \dot{m}_{inlet} \tag{3}$$

This implies that on a per unit mass basis, $\dot{m} = \dot{m}_{outlet} = \dot{m}_{inlet}$:

$$q + w_s = \left[u + \frac{P}{\rho} + \frac{V^2}{2} + gz\right]_{outlet} - \left[u + \frac{P}{\rho} + \frac{V^2}{2} + gz\right]_{inlet} \tag{4}$$

Since the flow is considered incompressible, the inlet and outlet velocities are equal by Equation (3) assuming that the inlet and outlet areas are approximately equal. In addition, negligible change in potential energy occurs across the pump, resulting in

$$\left(\frac{P}{\rho g}\right)_{outlet} - \left(\frac{P}{\rho g}\right)_{inlet} = \frac{w_s}{g} - \frac{u_{out} - u_{in} - q}{g} \tag{5}$$

The last group of terms represents frictional losses and is grouped into a frictional head loss term, h_f. Similarly, expressing the shaft work input into the pump as a shaft work head term, h_s, yields:

$$H = \frac{1}{\rho g}\left(P_{outlet} - P_{inlet}\right) = h_s - h_f \tag{6}$$

Now, H is the "net" or "pump" head and is the primary output parameter for a pump. Note that this is the difference between the shaft work and the frictional head.

The energy ultimately delivered to the fluid results from the difference between the input energy and the energy lost to friction, both mechanical and viscous, and losses due to pump leakage. The power delivered to the fluid is by tradition termed the "water horsepower" or *whp*:

$$whp = \rho g \dot{V} H \tag{7}$$

where $\dot{V}$ is the volumetric flow rate of the fluid. In contrast, the power required to drive the pump is termed the "brake horsepower" or *bhp*:

$$bhp = \omega T \tag{8}$$

where T is the measured shaft torque and ω is the shaft rotational speed in radians per second.

The overall efficiency of the pump is defined as the ratio between the power delivered to the fluid and the pump input power,

$$\eta_{pump} = \frac{whp}{bhp} = \frac{\rho g \dot{V} H}{\omega T} \tag{9}$$

This overall efficiency is a function of both mechanical and fluid mechanical losses. Contributing factors to the overall efficiency are viscous frictional effects and mechanical frictional effects in the bearings, packing and other contact points in the pump.

The use of performance or characteristic curves to present the operating characteristics of a pump is commonly done in industry. Characteristic curves can be used to aid engineers in the selection of pumps needed for their process and in the determination of the maximum efficiency of a pump over a range of operating conditions. These curves typically provide a functional relation of pump head, efficiency and brake horsepower plotted versus volumetric flow rate as shown in Figure 1. Other metrics shown in Figure 1 include the Best Efficiency Point or BEP and respective values of pump head, brake horsepower and volumetric flow rate, all designated with a superscript "*", at the BEP. Additionally, the maximum pump head and volume flow rate are designated shutoff head and free delivery, respectively.

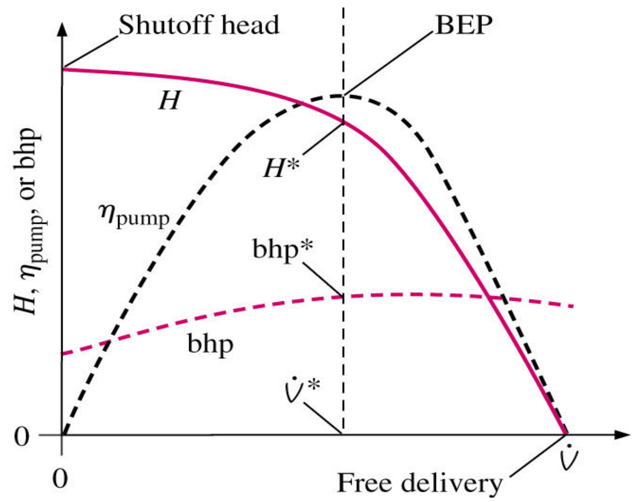

Figure 1: Typical Pump Performance Curves
Courtesy McGraw Hill Higher Education, Used by permission

Overview of the Desired Centrifugal Pump Test Bed

Centrifugal pumps are used to move liquids from one place to another; therefore, they prove to be a useful tool when trying to teach students the relationships between pressure or head, volumetric flow rate, shaft rotational speed, and input and output powers. It is intended that the test bed provide students with an educational instrument that they can use to perform different experiments to demonstration the physical and functional relationships between these parameters.

Based on the background outlined, the test bed designed by the students must be capable of measuring pressures (pump inlet or suction and outlet or discharge sides of pump), volume flow rates, pump shaft rotational speeds, shaft torques or forces with moment arms and water temperature (i.e., water properties dependent on temperature – density). Manually operated valves at the pump inlets and outlets should be used to control the water flow rate and to assist the student experimenter in intuitively arranging the flow for single and multiple pump - series and parallel - configurations. A schematic of a test bed comprising several of these attributes is shown in Figure 2.

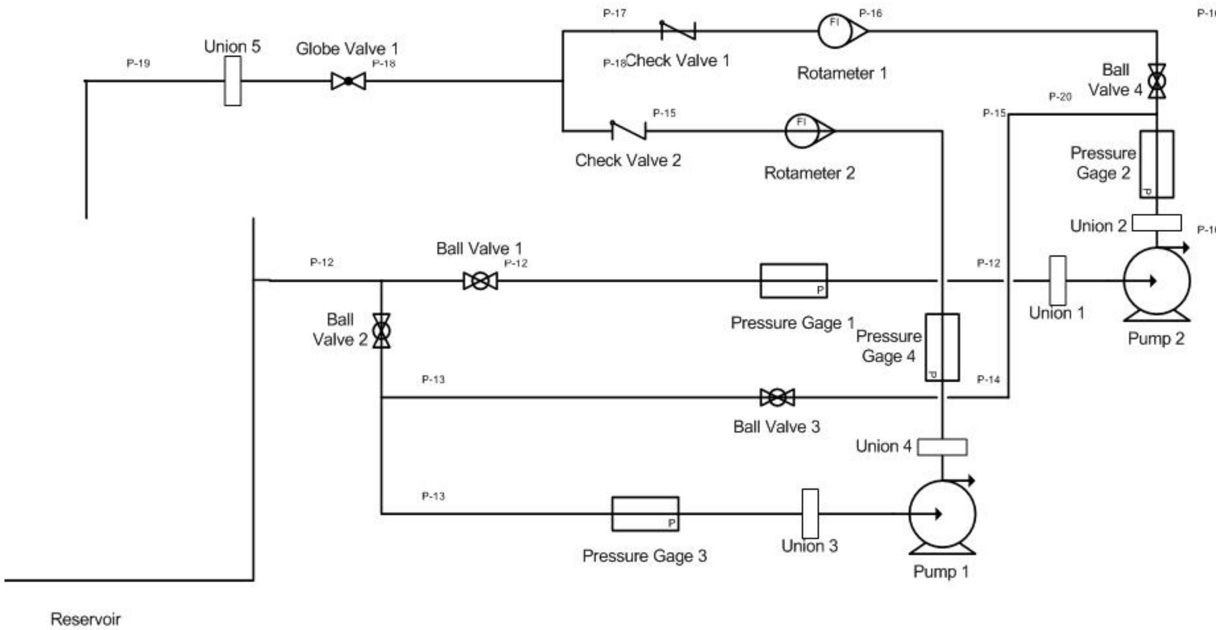

Figure 2: Schematic of Proposed Centrifugal Pump Test Bed

The intended outcomes of the experimental investigations performed will support student learning through the development of pump performance curves under various operating configurations - single and multiple pumps and the determination of the efficiency of the pumping system and of the impact to pump performance when using different diameter impellers or when operating at different motor speeds.

A useful innovation by the student design team was the capability of modifying pump impeller size by the student experimenters. It is common practice in the pump industry to offer several choices of impeller diameter for a single pump volute casing. There are several reasons for this: (1) to save manufacturing costs, (2) to enable capacity increase by simple impeller replacement, (3) to standardize installation mountings, and (4) to enable reuse of equipment for a different application.[4]

The design team also recognized that varying speed and changing impeller diameter would provide the mechanical engineering student performing these experiments with the opportunity to validate the similarity rules for a pump family. For geometrically and dynamically similar pumps operating under different conditions *A* and *B*, dimensional analysis and the resulting Π variables can be used to develop the following ratios or similarity rules for the pump head, *H*, volume flow rate, $\dot{V}$, and brake horsepower, *bhp*:

$$\frac{H_B}{H_A} = \left(\frac{\omega_B}{\omega_A}\right)^2 \left(\frac{D_B}{D_A}\right)^2 \tag{10}$$

$$\frac{\dot{V}_B}{\dot{V}_A} = \frac{\omega_B}{\omega_A}\left(\frac{D_B}{D_A}\right)^3 \tag{11}$$

$$\frac{bhp_B}{bhp_A} = \frac{\rho_B}{\rho_A}\left(\frac{\omega_B}{\omega_A}\right)^3\left(\frac{D_B}{D_A}\right)^5 \tag{12}$$

These similarity rules are useful to scale from model to prototype or to assess the impact on the physical parameters of head, flow rate and input power when changing pump rotational speed or impeller diameter, *D*.

General Centrifugal Pump Test Bed Design Criteria

In order to determine the direction of this project, general design criteria were established to provide the student design team with the necessary guidelines in which to proceed. The criteria selected below were presented to their faculty advisor for approval and were considered Acceptance Criteria. These Acceptance Criteria are strict guidelines for student design team to adhere to throughout the project, which were validated through testing upon project completion:

- The centrifugal pump test bed must be easily configurable through the use of manual valve adjustments for series and parallel operation.
- The centrifugal pump volute casing must be easily removed to facilitate installation of alternative impeller designs – diameter and vane modifications.
- The centrifugal pump motors must be driven by variable frequency controllers that are programmable for different speeds and for constant or varying torque. The motors have a maximum speed of 3450 rpm.
- The measurement systems in the test bed must be manual and visual to enhance the student learning experience through the collection and reduction of pump performance data.
- The entire device must be durably and rigidly built to endure a minimum of 5 years of laboratory service.
- The centrifugal pump test bed must be built within the budget provided by ASHRAE and ME Program at Western Kentucky University.

The centrifugal pump test bed, which was constructed to meet these criteria, is shown below in Figure 3 and its major components, fabricated and purchased, are discussed in the following sections.

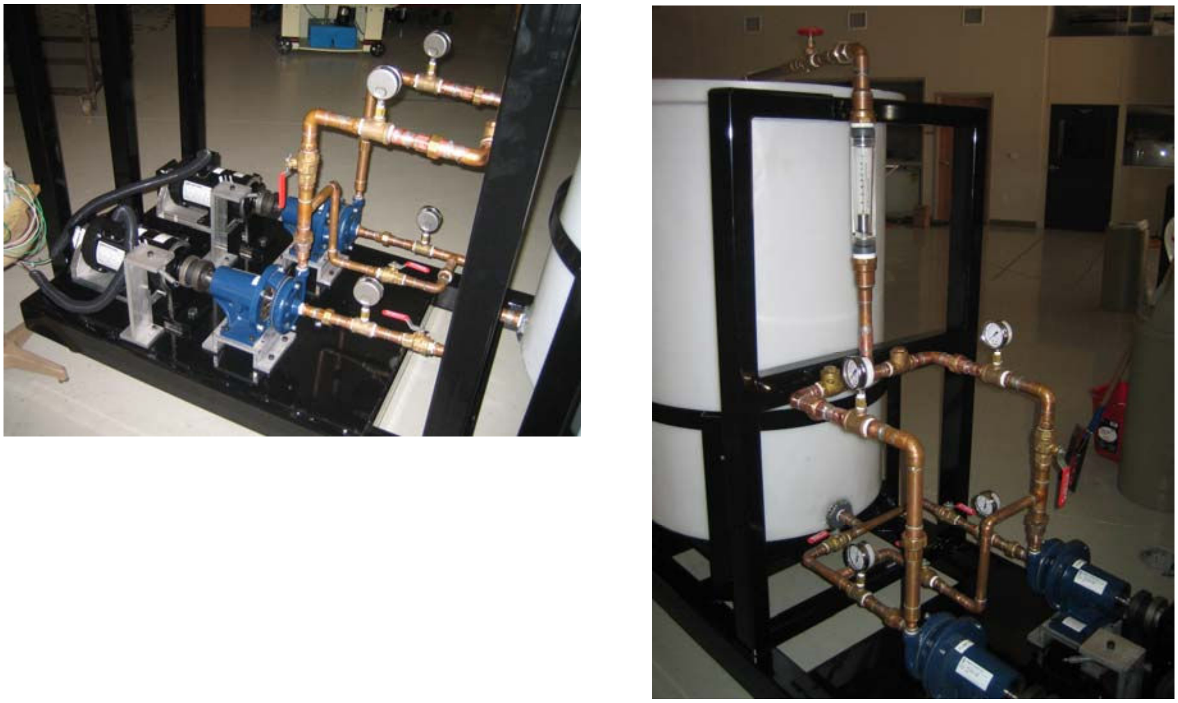

Figure 3: Western Kentucky University Centrifugal Pump Test Bed

Design and Selection of Major Test Bed Components

The student team researched feasible options for the various components of the system in the fall semester 2006, performed technical calculations and professionally justified all necessary aspects of the centrifugal pump test bed. The major components that they designed or integrated into their final system included the bench frame, reservoir, pump motors and variable frequency drives, volute casings, pipe network, motor and volute casing mounts, pressure gauges, flow meter, force gauge and tachometers. Each of these components is briefly described below.

- Bench frame material was selected and designed with stress and deflection analysis performed in the COSMOSWorks®. Based on the analysis results, the bench frame was constructed out of 3” x 4” and 2” x 3” low carbon steel rectangular tubing and platform of 11-gage sheet low carbon steel. Bench construction was performed in the Engineering Prototype Facility (EPF) and powdered coated to inhibit corrosion.
- A 100-gallon polyethylene circular tank was selected for the water reservoir. It included a steel stand engineered to support the maximum water load.
- The pump motors were 1-hp, 230-volt with single to three-phase conversion, which were selected with variable frequency controllers that were programmable for different speeds and for constant or varying torque. The selected motors have a maximum rotational speed of 3450 rpm.

- The pump volute casing included: an impeller with four backward curved vanes and a nominal diameter of 3.94”, seals, bearings, and a power transfer frame.
- The piping network was constructed of 1” and ¾” type L copper tubing and comprised of all appropriate elbows, tees, reducers, diameter change adapters, and valves.
- The motor mounts were constructed of ½” steel; and incorporated a steel shaft with bearings to allow for torque or force measurements *in situ*.
- The pump mounts were constructed of ½” aluminum.
- Motor couplings were required to couple the motor shafts to the pump shafts. A hub with a bore of 5/8” and a hub with a bore of 1-1/8” with the matching rubber compliance elements were selected to provide this mating structure.
- Two different pressure gages, one for the suction side and one for the discharge side of the pump, were selected. The discharge side gages were standard precision dial gages with a range of 0-100 psi, and the suction side gages were similar type with a range of -30 in-Hg to 15 psi. The required measurement ranges were confirmed via simulation with AFT Fathom[5].
- The volumetric flow meter selected was a rotameter with a measurement range from 4-40 gpm. Again, the maximum volume flow rate was determined prior to selection via simulation with AFT Fathom[5].
- Tachometer displays and optical sensor were chosen to take shaft rotational speed measurements. The displays can display up to 9,999 rpm and the sensors can read up to 999,999 rpm.

These major test bed components, their purchased, and if applicable, associated fabrication costs are shown below in Table 1:

Table 1: Centrifugal Pump Test Bed Project Bill of Materials and Cost

Component	Supplier	Description/Part Number	Cost
Bench Frame – Materials and Fabrication	Various Local	Square Tube, Plate and Angle Low Carbon CR Steel Weldment with Powder Coat	$1500
Reservoir	Tank Depot	Heavy Duty Polyethylene/100 Gallon Open Top/32” Diameter X 42.5” Height with Steel Stand	$350
Pump Motors - 2 VFD’s - 2	Automation Direct	1 hp Micro MAX AD Motor/Y364 GS1 Series Drive/GS1-21P0	$440 $660
Motor Mount Hardware (Student Fabricated) Shaft Coupling Hardware	 McMaster Carr	Cold Rolled Steel Plate Weldment with Powder Coat Multi-Flex Shaft Coupling, 5/8" and 7/8" Bores / 6507K2 Multi-Flex Shaft Coupling Rubber Element / 6507K1	$135 $20 $15

Table 1 Centrifugal Pump Test Bed Project Bill of Materials and Cost - Continued

Component	Supplier	Description/Part Number	Cost
Pump Volutes with Impellers – 2 Impellers – Multiple (Student Fabricated)	Sherman & Schroder Equipment Co.	Price Pump / F50 Volute & Various Spare Mechanical Hardware Aluminum Stock and CNC Fabrication	\$890 \$215
Piping, Fitting and Valve Hardware (Assembly Student Fabricated)	Plumbers Supply Co.	1/2" and 3/4" Type M Copper Pipe Unions, 90° Elbows, Tees and Reducers, and Valves	\$60
Pressure Gages - 4	McMaster Carr	Dial Face, 2.5", Bottom Connection / 4000K722	\$50
Rotameter - Volumetric Flowmeter	Omega	Acrylic Rotameter, 4-40gpm / FL75F	\$240
Force Gages - 2	Wagner Instruments	Force Dial, Decimal Pounds, 10 lbf x 0.1 lbf Increments / FDK10	\$350
Tachometer Optical Sensor Tachometer Display	McMaster Carr	Optical Sensor, 1 - 250,000 rpm / 85187T93 Panel Mount Tachometer, 5 - 99,990 rpm, 4 Digit Display / 14215T11	\$135 \$150
Project Total			\$5210

An additional major component discussed in the next section is the design and fabrication of pump impellers. As indicated above, the purchased volute casing included an impeller with four backward curved vanes and a nominal diameter of 3.94"as shown in Figure 4. The student design team felt that modification of this geometry by changing the impeller diameter, the vane geometry and the number of vanes should be an option provided to the student experimenter. A method was researched for impeller design and the EPF infrastructure supported impeller fabrication.

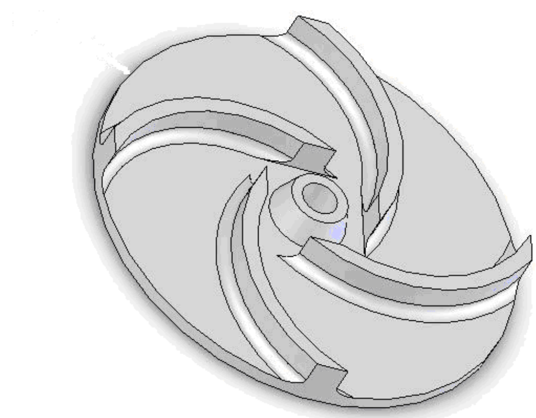

Figure 4: Standard Four Vane Impeller

Design and Fabrication of the Pump Impellers

One of the unique aspects of the test bed is the ability of the student experimenter to investigate alternative impeller designs. The volute casing assembly selected for the test bed included an impeller with four backward curved vanes and a nominal diameter of 3.94 inches. A design methodology was used to develop the profiles of the following impellers:

- Four Vane Impeller as Purchased
- Four Vane Impeller Geometrically Similar with Smaller Diameter

In order to validate the process, the purchased profile was designed using an impeller design methodology[6]. This process yielded a geometrically similar profile of the purchased four vane, 3.94" diameter, impeller within the limits of this analytical method. Key parameters, including exit and entrance angles and velocities, were in suitable agreement. The profile generated was then modeled in SolidWorks®, and the model was imported into SurfCam Velocity® where a series of virtual processes digitally machined away the stock material leaving only the necessary geometry to create the impeller. Through post processing, the students generated the specific CNC codes for the HAAS CNC Vertical Machining Center. To verify dimensionally and to ensure that the integrity of the data obtained in the design method had not been comprised through this process, the four vane impeller was fabricated from aluminum as shown in Figure 5.

Figure 5: HAAS CNC Vertical Machining Center Fabricating Prototype 4 Vane Impeller

Once verified, the same design method was used to create the profile for the smaller diameter impeller and it was fabricated in the same process. The performance of these two geometrically similar impellers was analytically compared using Equations (10) and (11). Within the uncertainty of the pressure and volume flow rate measurements, the head versus the volumetric flow rate relationship for these two impellers was also measured on the test bed and found to be in good agreement with this analytical prediction.

Project Assessment and Outcomes

Over the past six years, the ME faculty at Western Kentucky University have developed and implemented a professional experience sequence for ME students pursuing a baccalaureate degree that is consistent with overall mission of the engineering department [7] (the complete Department of Engineering mission statement is found at http://www.wku.edu/ engineering/depmiss.php):

…to produce, as its graduates, competent engineering practitioners. An engineering practitioner is one who has a foundation of basic science, mathematics, and engineering knowledge, combined with practical knowledge and experience in applying existing technology to contemporary problems. … Program curricula will be project-based. Students will have sufficient opportunity to engage in project activities to support development of a clear understanding of engineering practice. … Projects that provide opportunity to accomplish design, development, and implementation should be available.

A Professional Component Plan has evolved into a framework for defining, teaching, assessing and improving students' competencies as they implement mathematics, basic science and engineering science in professional experiences. As required by EAC of ABET's Criterion 4: "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints".[8] To accomplish this, the ME Program Professional Component Plan has four areas:

- Engineering Design Plan (teaching and practicing of design skills)
- Professional Communications Plan (conveying designs and interacting with peers)
- Computer Skills Plan (teaching and implementing of design tools)
- Engineering Ethics Plan (evaluating and practicing appropriate professional behavior)

Engineering Design Plan and its associated experiences combine a structured approach to solving problems with an appreciation for the art of engineering. Professional Communications and Computer Skills Tools are introduced and then required throughout the four-year sequence to support the execution of design projects. The Engineering Ethics component provides students with a framework for understanding professional expectations and techniques for clarifying the ambiguity that is common in ethical dilemmas.

The primary purpose of the Professional Component course sequence is to link all these skills to engineering design and to assess the progress of student capabilities through the curriculum. The integrated structure of the Professional Component courses provides a framework for building upon previous coursework, assessing student progress often, and more quickly adjusting course coverage based on prior assessments to effectively assure that graduates of the program are capable of practicing as engineers upon graduation.

The Professional Component as defined by EAC of ABET Criterion 4 has two major areas. The first area, Curricular Content, deals with whether the program provides the students with course-specific content in the areas of mathematics, basic science, engineering science, and General Education. The second area, Extra-Curricular, deals with the professional experiences of a student pursuing their degree: "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints."

The mechanical engineering program at Western Kentucky University is becoming established, with the fifth cohort of seniors currently progressing towards a May 2008 graduation. As an undergraduate-only engineering program, the ME faculty members place a strong emphasis on graduates possessing this Extra-Curricular professional competence. To achieve this outcome, it is necessary to provide students with the opportunity to acquire design tools and skills, as well as competency in mathematical and technical analysis, and communication. Throughout the four-year plan of study, the ME students receive coordinated instruction from both thermal-fluids and mechanical systems faculty, and are required to demonstrate varied levels of professional competence in both tracks.

The ASHRAE funded project provided an excellent vehicle for this integration and major design experience to occur. The three students on this project team demonstrated the technical competencies from a number of engineering science courses to successfully design, build and test the Centrifugal Pump Test Bed. The fall and spring two-course sequence coupled with ASHRAE's Undergraduate Senior Project Grant Program Student were partnered very effectively to achieve our program outcomes. An external sponsor, who required periodic status reports, also added a level of creditability to the project.

Course Assessment and Outcomes
The course, which housed this DBT project is a continuation of ME 400 and provides students with a capstone engineering design experience. The final product of ME 400 was a design proposal document that is executed in ME 412. The grading in ME 412 continues to be 2/3 team based and 1/3 individual. This year there were more teams than ever (8 vs. 3, 5 and 4 in prior years), more students and better overall quality of project execution. One project finished a week late, a second project had a major scope adjustment due to external factors, but overall the year was a considerable success.

The 22 students, divided into eight teams executed two projects for industrial sponsors (MTD and Logan Aluminum), two projects for entrepreneurs (Comfort Tech and Fabric Cutters), two projects for Western Kentucky University organizations (Agriculture, WATERS Lab), and two projects for the Mechanical Engineering Program (ASHRAE and Materials). The projects involved the design, construction and testing of final systems, prototypes or research initiatives; total project budgets was approximately $40,000.

The expected course outcomes for ME 412 are as follows:

1. Use structured problem solving techniques, appraise the needs of clients, produce product/project definition documents, and propose appropriate engineering solutions.
2. Execute a design from inception through completion, and convey/document solutions in a wide variety of formats – including effective oral business presentations, and clear, concise project documentation that flows from general to specific.
3. Successfully manage projects using management tools such as timelines, responsibility charts, etc.
4. Participate effectively in multi-disciplinary teams, demonstrating that they are effective team members and evaluating the performance of team members.

The student performance is assessed via their scores on intermediate activities related to their final projects (design reviews, update presentations) and final project results (reports, presentations, demonstration). The assignments are matched with the course outcomes. A target score of 8.0 for all outcomes is based on the need for students to demonstrate competence in these professional components. Faculty evaluation based on graded student performance and students' self-evaluation all indicate that students have achieved the course outcomes as shown in Figure 6.

In general, students are proving themselves to be effective team members, are capable of demonstrating structured problem solving and are successfully managing projects from ; inception to completion; however, they are less capable of providing quality feedback regarding the performance of their peers.

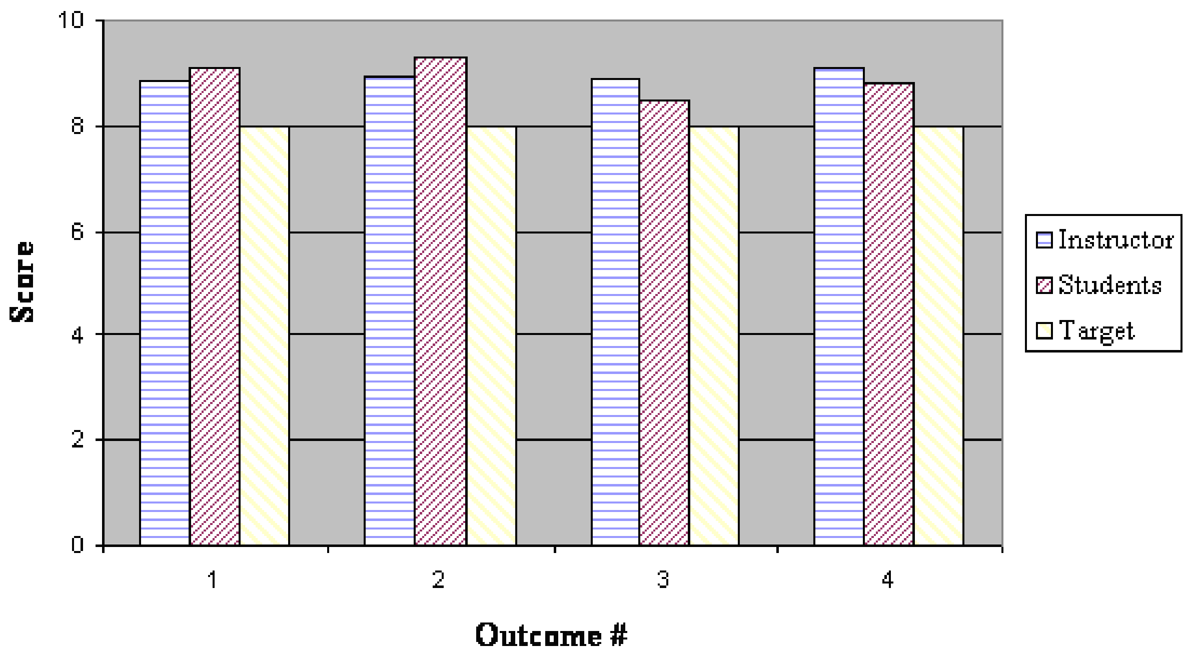

Figure 6: ME 412 Course Outcome Assessment

Currently, there are 18 students, five projects, and four faculty members involved; lessons from the past years allow us to effectively manage these experiences. The program Professional Plan is well in place and appears to be working to evaluate activities and make decisions regarding these courses to properly address the Professional Component of the program.

Conclusions

Overall this project provided the experiences necessary to achieve the desired outcomes of our ME Program Professional Component Plan. In particular, this project was very suitable to the two course sequence for our capstone senior project, ME400 – Mechanical Engineering Design (Fall semester - 2 credit hours) and ME 412 – Mechanical Engineering Senior Project (Spring semester - 3 credit hours).

The students on this project team demonstrated engineering design principles in the selection of the pumps, flow meters, sizing and design of the piping, design and selection power and control systems, and design and implementation of the variable pump impeller and speed controls. The design and selection of these project components were constrained by both financial and time lines typical of a "real world" engineering projects and were managed by two faculty acting as advisor and industrial contact, respectively, to further give the student a "real world" experience in highly dynamic environment with multiple "managers".

Other components of the plan were exercised as well. Students drafted both the interim and final project status reports and the faculty edited to meet the specific guidelines of the sponsor. Additionally students presented this project at the 37th Annual WKU Sigma Xi Student Research Conference where their work was favorably reviewed by peers and other faculty within the university community and will also present this project to the Department of Engineering and our Mechanical Engineering Advisory Committee.

In addition to the senior students on this project team, the other benefactors of this test bed will be future students in ME 330 – Fluid Mechanics and ME 440 – Thermal Fluid Systems Laboratory. These traditional engineering science and hands-on laboratory courses will have a centrifugal pump demonstration bench for use in the learning of the interactions of centrifugal pumps, which can then be compared with their theoretically predictions.

Acknowledgements
The authors acknowledge the contributions of the CentriPump student team: Mary Elizabeth Baker, Elizabeth Schmale and Luis Villalpando. The staff engineer, Chris Moore, was instrumental in supporting fabrication of the various impeller designs and of the test bed frame and the pipe network.

Funding has been provided by a grant from the American Society of Heating, Refrigerating and Air-Conditioning Engineers under the Senior Undergraduate Project Grant Program. The intention of this grant program is to provide engineering schools with funds that help to increase student knowledge and awareness of the HVAC&R industry.

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