Journal of
Problem
Based
Learning
in Higher Education

VOL. 5, NO. 2, 2017 – Page 48-58
http://dx.doi.org/10.5278/ojs.jpblhe.v0i0.1826

Application of PBL in the Course Fluid and Electrical Drive Systems, Case Study: Manufacturing an Automated Punch Machine

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ABSTRACT

The PBL unit of fluid and electrical drive systems is taught in final semester of undergraduates in mechanical engineering department of the Australian College of Kuwait (ACK). The recent project on an automated punching machine is discovered more appealing to both students and instructors in triggering new ideas and satisfaction end results. In this case study, the way this PBL unit is coordinated and facilitated is explained. Two examples of student works are presented. The aim is to expose the students to real world engineering problems but in a satisfying manner. Similar to real life problems for engineers, restrictions are applied for the students on costs, availability of ACK facilities, and application of automation tools. Students are directly engaged by using technical standards on punching heads and dies, standard tensile testing of plates, and so on. Arduino microprocessor programming, an open-source hardware and software electronic platform, and electro-pneumatic devices are adopted for developing the automated punching machine. The goal of the PBL course is to acquaint students learning based on the concepts of team working, engineering design, professional manufacturing, and sequential testing of the end product. It is found that students achieved their best and developed new skills in this PBL unit as reflected in their portfolios.

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Keywords: Arduino processing, Automation, Fluid and electrical drive systems, Project based learning, Punching machine.

INTRODUCTION

The concept of PBL (problem based learning) was probably initiated from McMaster University (De Graaff & Kolmos, 2007) although the idea was applied in nursery schools, medical sectors, and other areas earlier (Schweinhart & Weikart, 1997; Van der Vleuten et al., 1991; Sang, 2001; Schmidt, 1993). The acronym PBL was later extended to "Project Based Learning" in engineering discipline (De Graaff & Bouhuijs, 1993; De Graaff et al., 2006). A PBL facilitator guide was developed in Australian College of Kuwait (ACK) for consistency of delivery in all PBL units presented in ACK. In these units the instructor task is described as "facilitator" rather than general lecturing (Jaeger & Adair, 2015; Jaeger, 2017). The effective learning of students in PBL is described by project oriented, student self-directed, activity-based, real life context, analytical thinking required, and team-based learning. In the PBL environment, students may imagine that they are hired as engineers by a company (ACK) and they operate under a line manager (course instructor). During class sessions, students may consider the classrooms equipped with computers as their workplace, and an engineering workbook and a reflective journal as their tool. In the ACK PBL environment, the emphasis is on learning outcomes (Jaeger, 2017); therefore, students may pass the PBL units if they satisfy the learning outcomes of the unit and perform their tasks professionally. However, more credential will be given to successfully executed projects.

THE UNIT OF FLUID AND ELECTRIC DRIVE SYSTEMS

The unit of fluid and electrical drive systems, delivered in the department of Mechanical Engineering at ACK, introduces fluid and electrical drives and the design of integrated drive systems for use in industry (Sedaghat et al., 2016). It covers comparison of characteristics, construction, selection, design and operation of fluid and electric drives and drive systems, use of mathematical models to analyze performance, machine protection and control schemes, and evaluation of drive system performance. Students apply formulas and explain and record calculations. They adopt professional approaches to work in teams and learn collaboratively to manage and complete projects, to lead their own learning, and to communicate professionally using discipline language to investigate, design and check their work, and present designs and problem solutions, and use suitable software to develop their prototypes.

The course objectives and student learning outcomes of this unit are listed as (Sedaghat et al., 2016):

1. Describe and explain characteristics of fluid drive and electric drive systems, design industrial drive applications to meet performance specifications, and justify selections made and designs approaches.
2. Compare construction and operational characteristics of DC and AC electrical machines and fluid drive machines.
3. Design and explain mathematical models to analyze drive performance.
4. Design and explain machine protection and control schemes for electric and fluid drives in typical industrial applications.
5. Evaluate the performance of the drive systems using appropriate assumptions, non-linear models, solution techniques and simulation software
6. Describe and explain DC and AC electrical energy and generation and uses in a sustainable development environment
7. Apply formulas and record and explain processes used to calculate solutions related to electrical power and energy and their conversions
8. Work and learn demonstrating professional approaches to teamwork, management and completion of projects, and collaborative learning
9. Apply professional self-management principles and independent learning approaches to ensure competence and experience is gained in all content areas
10. Communicate effectively using appropriate terminology, symbols and diagrams related to electric and fluid drives and use professional approaches to investigate problems, justify and check designs and present solutions

PUNCHING MACHINE AS THE CASE STUDY

The case study was conducted in the department of mechanical engineering at the Australian College of Kuwait in fall 2016. The project brief of the case study is listed below.

Case study: Automatic punching machine for a circular flange

Project Brief:

> As a team of engineers, you are requested to develop the best idea, design, and product. At the end of semester, all products will be evaluated based on the product evaluation criteria and the students who have created the best product will be awarded with an official "ACK best automatic punching machine award" and allowed to attend the graduation exhibition. On the other hand, you will be evaluated 100% on portfolios with respect to the 10 learning outcomes listed in your unit outlines. A criteria sheet provided suggest four categories of Unacceptable, Acceptable, Good, and Excellent for your portfolios evaluations.

Based on the provided grading rubric, student's overall mark in this PBL unit will be calculated.

Student design should fulfill the following:

1. Consideration of relevant codes and standards, as well as industry practices.
2. Required material should be available in Kuwait.
3. Assumption of all missing information.
4. Available budget: maximum 50 KD; teams should buy only materials not available at ACK.
5. Preliminary design (planning) should be completed to minimum size and presented on the beginning of week 6 by student teams (maximum 3 students per team).
6. All implementation and build works must be conducted in ACK under supervision of course Instructor and Lab or Workshop technicians.
7. Managing the design/production processes (including submission of design, quality control, time monitoring, budget control, organizing meetings, project management, etc.).

The final product should fulfill the following criteria:

1. Satisfying the seven requirements listed above;
2. Demonstration of creativity, innovation, and novelty;
3. Demonstration of actual operation on handling a glass;
4. Stability and uniformity of precise operation at real work condition;
5. Automatic operation and demonstration for one working cycle; and,
6. Quality of the manufactured product.

Example of the circular flange is shown below. The material (preferably non-metallic) and the number of holes for the flange are arbitrary; therefore, the machine should automatically create the holes in the flange one-by-one using appropriate programming in Arduino processor.

The best project award will be given to the smallest size designed, manufactured and operated machines.

Figure 1: Example of a circular flange for operation under the punch machine

METHODOLOGY

Students in the PBL unit were introduced to the projects briefs. They were allowed to form teams of maximum three members. The students had two sessions of two hours in classroom with the instructor (facilitator) and one session of two hours in the fluid mechanics lab on weekly basis. The lab activities include practicing with five electro-pneumatic circuits and five sessions in practicing with Arduino processer and programming during the ten-week program. The first six weeks of the course is allocated to the planning phase while the remaining six weeks is focused in implementation phase. During the first six weeks period, students are provided with short lectures in pneumatic and electrical systems, a training session on FluidSim the software on electro-pneumatic circuit design, and investigating in standards on punch heads and testing plates using tensile testing equipment. Progress of planning of students is monitored on a bi-weekly basis. Weekly meeting minutes and agenda of student teams are discussed during meeting with facilitator. The entries to students' workbooks and reflective journals are monitored weekly or bi-weekly by the instructor.

By the week six, students have to complete their planning by providing 3D and 2D drawings of the mechanical part of their automated machine. A reflective paper on AC and DC machines is submitted at this week preferably on outcome of consulting with an industrial practitioner or from the selected electrical drive machine of each team. The developed designs of student teams are presented in the week six using PowerPoint presentation. Feedback and criticisms are received from an internal examiner, lab instructor, the course instructor, and also other student teams in the class during the presentation.

After the week six, the implementation phases are conducted and fully supervised by ACK faculty staff in the ACK labs, workshop, and other internal or external advisors. The students have to familiarize themselves with automation and application of the Arduino micro-processing programming, testing standard samples of plates in the tensile testing lab if required, and acquainted with other software to design, analysis, and test their manufactured machine. By week twelve, all projects have to be completed, tested and evaluated by course instructor and the internal committee of one or two faculty members. Portfolios are submitted in week 13 and evaluated by the course instructor. In weeks 14 or 15, the final presentation of teams including PowerPoint and Poster presentation are conducted and individual viva-voce is carried out by an examiner panel of two or more faculty PhD holders. The evaluation is based on satisfying 10 learning outcomes. If one learning outcome is unacceptable or the attendance of a student is below 80% then the student has to repeat the unit.

RESULTS AND DISCUSSION

Team Design 1

Team 1 designed the punch machine shown in Figure 2 and manufactured the machine as shown in Figure 3 to create holes in a gasket material. The design uses a stepper DC motor with 200 steps (1.8 deg/step) to turn the flange at equal angles and a 32 mm pneumatic cylinder to exert the punching force. The electro-pneumatic circuit is controlled by an Arduino microprocessor and is programmed to make an optional number of similar sized holes in the flange. The compressed air is supplied with 5 bar pressure at the ACK Fluid Mechanics lab. The backward and forward movements of the piston's head which is connected to a standard size punch head (AW Precision LTD, 2017; Edwards, 2017) and operation of the stepper DC motor are controlled by the relay board which is programmed to work using Arduino microcontroller. The press force is calculated by adding two forces of cutting and stripping force as follows (Goyal et al., 2015):

$$F_{Press} = F_{cutting} + F_{Stripping} \qquad (1)$$

The cutting force is calculated by (Goyal, 2015):

$$F_{cutting} = \pi\ d\ t\sigma_{tensile} \qquad (2)$$

The stripping force constitutes 15 percent of the cutting force.

For the chosen gasket material, it is decided to use tensile test facility at the ACK Civil lab. Hence, the standard ASTM D-638-02a (2003) shown in Figure 4 is adopted to design the shape and sizes of a testing sheet of the gasket material. The deigned gasket sheet was tested using the tensile testing machine.

The team used a wood piece under the flange sheet instead of a die. This turns out later as a clever decision for creating effective punching holes in the gasket material.

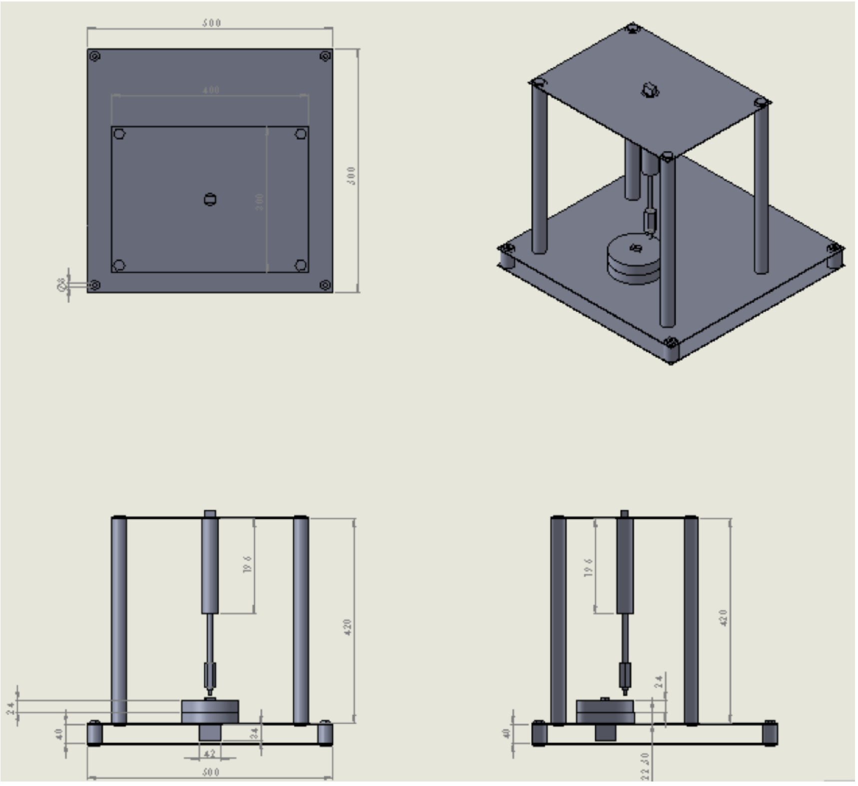

Figure 2: Design of the punching machine, three views drawings of the punch machine

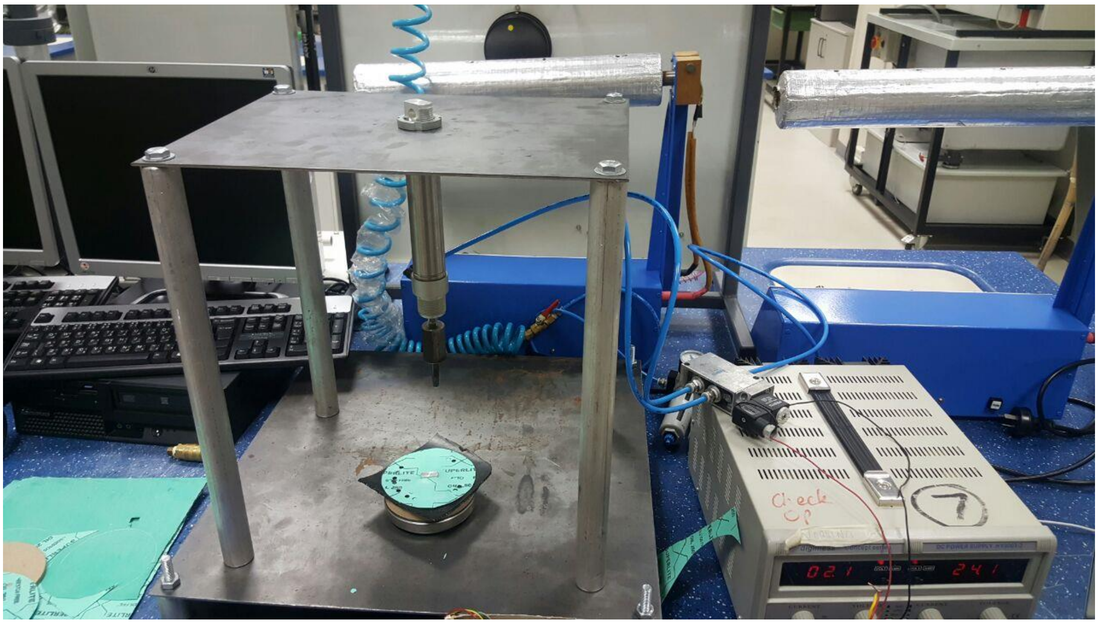

Figure 3: Team 1 punch machine in testing

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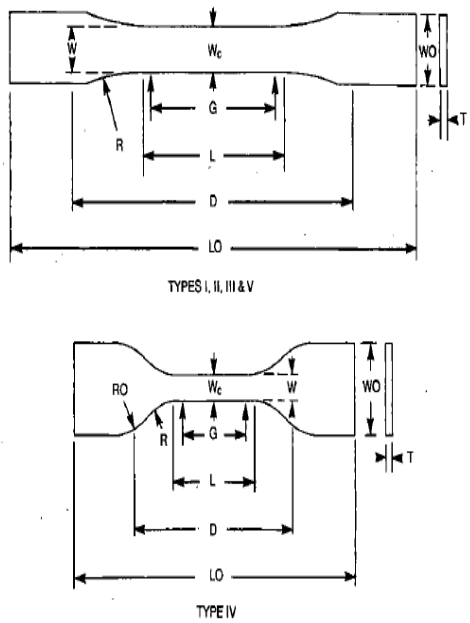

Specimen Dimensions for Thickness, *T*, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

Figure 4: The ASTM D-638-02a standard shape for tensile testing of sheets

Team Design 2

Team 2 has used a punch head and a die element in their design (see Figure 5). They faced several challenges to complete their project. They have listed their challenges as follows:

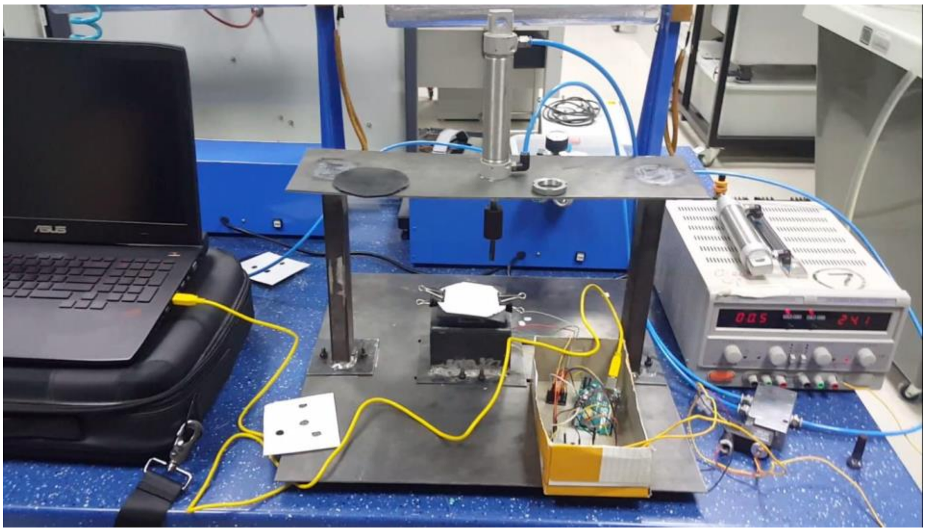

Figure 5: The punch machine of team 2 in testing

Challenge 1: The first challenge faced is tuning the punch head to directly pass through the flange sheet and into the die element due to slightly misalignment.
Solution 1: The team has used a smaller diameter punch head to adequately pass through the flange and the die although the quality of the holes is slightly affected.
Challenge 2: The team faced a problem with mounting the motor in a secure place to prevent it from being damaged in the case the punch head hits the die piece below the flange.
Solution 2: The motor is mounted into a stand by bolts which allow the shaft of the motor to not absorb impact force of the punch head.
Challenge 3: One problem is that the height of the machine has passed the allowed limit due to the pneumatic piston being mounted inside the frame, and the team has to give more room for the extension of the rod.
Solution 3: The problem is solved by shortening the steel bars of the frame to enable to mount the pneumatic cylinder on top of the frame as shown in Figure. This approach reduced the overall height of the machine while maintaining the clearance needed for the rod extension.
Challenge 4: The main problem this team faced was with the stepper motor as it didn't work as planned using the programmed code in Arduino. They discovered the motor was factory defect when they checked with the supplier of the unit.
Solution 4: The team replaced the motor malfunctioning unit with a brand new one.
All team members worked professionally and achieved their best in this team work. The teams have enjoyed their learning journey by utilizing the standards on punching head designs and testing plastic sheets and have successfully created holes in the flange sheets using their punch machine.

CONCLUSIONS AND RECOMMENDATIONS

The PBL unit of fluid and electrical drive systems is generally delivered in the last semester of undergraduates in mechanical engineering department of the Australian College of Kuwait (ACK). ACK has a rigorous plan to promote PBL courses in the Engineering departments, including Mechanical Engineering, to foster sustainable engineering development. Therefore, students who are enrolled in this course have the experience of passing three PBL courses before. This would allow students to familiarize themselves with the PBL style of learning.

The unit of fluid and electrical drive systems has progressively been improved over the past few years. This PBL unit is developed to educate our students with real life problems and challenges. Based on received feedback from students, the length of lectures are reduced to allow students to study the provided materials on their own pace, more examples of previous semester project shared with students, and the developed knowledge are shared among lab technicians, instructors, and new students.

Examples of what entries are expected in the individual workbooks and reflective journals are explained. Students are trained with assembly of pneumatic circuits in the lab, introduced to software FluidSim to simulate their pneumatic circuits, and five extra lab activities are added to introduce students to programming in Arduino microprocessor. These changes, together with the eagerness of ACK students to learn and to have hands on works, have produced a promising learning environment.

Most of the successful students in the degree program are now pursuing higher degree studies. As the school of engineering presents some of the students' achievement in PBL units in the exhibition day and as PBL scheme is introduced to the diploma program in addition to other degree PBL units, it may be suited to run a PBL exhibition day alongside the ACK PBL symposium day or side by side to the school of engineering graduation exhibition day. By sharing the details of course and reporting experiences we aim to provide some insight for implementation of the course in other institutions.

ACKNOWLEDGEMENTS

The first author wishes to cite and acknowledge the student teams, Team 1: Meshal Al-Hajeri, Bader Al Otaibi, and Meshal Al Mutari awarded the best ACK punching machine in 2016; Team 2: is Ali Dib, Mahdi Ali Daneshi, and Fatma Al Shatti.

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