Design and Construction of a Laundry Washing Machine Based on Programmable Logic Controllers: A Capstone Design Project

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***Abstract* — This paper describes one of the capstone engineering design projects implemented by Penn State Altoona BSEMET (baccalaureate degree in electro-mechanical engineering technology) students during their senior year. This project is titled "Design and Implementation of a Laundry Washing Machine" and is implemented using a programmable logic controller. At Penn State Altoona, the laundry washing machine is designed and built by individual students during a time period of one semester.**

The paper begins with a description of the BSEMET program.

Next, the paper describes the BSEMET capstone project design course (EMET 440). The course is titled Electro-mechanical Project Design and it is offered in the fourth year of the BSEMET program. This course deals with the planning, development, and implementation of electro-mechanical design project. The course includes formal report writing, project documentation, group presentations, and project demonstrations.

Finally, the paper describes one of the EMET 440 capstone design projects recently completed by students. The project consists of the design and implementation of a laundry washing machine using Allen Bradley SLC500 PLC. The paper presents the design specifications of this washing machine and provides details regarding its design and implementation. Recommendations for improvement in design are also provided.

***Index Terms* — Capstone design projects, electro-mechanical, programmable logic controllers, engineering technology.**

I. Introduction

The Accreditation Board for Engineering and Technology (ABET) is recognized in the United States as the sole agency responsible for monitoring, evaluating, and certifying the quality of engineering, engineering technology, and engineering-related education in colleges and universities [1].

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Any educational institution seeking accreditation of an engineering or engineering technology program has to demonstrate that the program in question clearly meets certain criteria as determined by ABET. The ABET 1999-2000 criteria for accrediting engineering technology programs include the requirement for providing technical design courses in the ABET accreditable engineering technology programs [2].

Quite often, a capstone engineering design course constitutes one of the many technical design courses provided by ABET accreditable baccalaureate engineering technology programs. A capstone engineering design course usually focuses on planning, development, and implementation of an engineering design project which includes project documentation, formal report writing and project demonstration. The capstone design course is usually offered in the senior year of the baccalaureate program. A capstone design course offered at Oregon Institute of Technology is described in [3].

This paper describes one of the electro-mechanical design projects conducted by the Penn State Altoona BSEMET students in the EMET 440 course. The course is titled Electro-mechanical Project Design and is offered in the fourth year of the BSEMET program.

II. Institutional Background

Penn State Altoona is one of 24 campuses making up The Pennsylvania State University system. It is the second largest of the 24 campuses and is a full-service residential campus located 42 miles from the research campus at University Park. Penn State Altoona became a four-year college within The Pennsylvania State University system in 1997 and offers baccalaureate degrees in eight majors. Penn State Altoona also offers associate (two-year) degrees in nine majors. Additionally, Penn State Altoona provides two years of course work for more than 160 Penn State majors. More than 3800 students attended Penn State Altoona during Fall 1999. During the 1999-2000 academic year, 239 minority students attended Penn State Altoona.

III. BSEMET Program Description

The Bachelor of Science in Electro-Mechanical Engineering Technology (BSEMET) program at the Penn State Altoona campus is five years old. The genesis for the program can be traced to industry's needs for people who can work on systems, machines and products that have both electrical and mechanical elements. The program emphasizes a breadth of knowledge in all fields of engineering technology related to typical manufacturing, production and assembly plant process.

The establishment of a BSEMET program at Penn State was motivated by the recognition of three facts: 1) that modern manufacturing and process industries are moving rapidly toward substantial, and in many cases, total automation, 2) that these industries are the major province for future engineering technology jobs, and 3) that much of what technologists will be expected to do in these jobs will require that they have knowledge of both mechanical and electrical systems and particularly of the problems and challenges associated with interfacing the two technologies. The goal of the Penn State BSEMET curriculum is to provide that knowledge. The BSEMET program of study supports instruction in the following areas:

- Inter-disciplinary concepts required for an understanding of mechatronic devices and systems.
- Operation, programming, and troubleshooting of integrated systems using data networks to link smart devices and intelligent machines.
- Operation, configuration, programming, and troubleshooting of systems using pneumatic, hydraulic, mechanical, and electrical parts locators controlled by single board machine controllers, programmable logic controllers, and microcomputers.
- Operation, programming, and troubleshooting of process control systems using single-loop and distributed PID control architecture.
- Development of written and verbal communications skills needed to present and sell projects to individuals and small groups.
- Development of the interpersonal skills required for work in concurrent design and production support teams.
- Development of a broad range of project management skills including project cost and payback analysis, quality management, conflict resolution, consensus building, and concept presentation.

The Penn State Altoona BSEMET courses comprise up-to-date and current technical content and are taught using state-of-the-art pedagogical techniques.

IV. Capstone Project Design Course

The description of the BSEMET capstone project design course (EMET 440) is as follows:

EMET 440 (Electro-mechanical Project Design) is a capstone project design course required for all the BSEMET majors. The course focuses on planning, development, and implementation of an electro-mechanical design project which includes formal report writing, project documentation, group presentations, and project demonstrations. The goal of this course is to demonstrate the ability to manage a major project involving the design and implementation of products with a mixture of electrical and mechanical elements as a member of a product development team. In this project-based course students are expected to effectively manage their time and team efforts to produce a finished product in the fifteen-week semester. No textbook is required. Bi-monthly progress reports, design notebooks, formal reports, and oral presentations constitute integral components of this course. Before beginning the projects, student teams are provided adequate training in project formulation and resource analysis, performance goals and team expectations, public presentations, public presentations of project work, and individual project supervision.

V. Design And Implementation Of A Laundry Washing Machine

The key objective of the laundry washing machine project is to design and implement an electro-mechanical system using a programmable logic controller (PLC). An Allen-Bradley SLC500 PLC is used in this project. The main interface software used is known as RS Logix which creates the programming environment in which the actual program is written before it is downloaded into the PLC.

The design specifications for the laundry washing machine are listed in [4]. These specifications are as follows:

OPERATION

The operator will select between the following modes of operation prior to pressing the START button.

Wash, Rinse, Spin
Hot, Warm, Cold Wash
Warm or Cold Rinse
Bleach or No Bleach
Fabric Softener or No Fabric Softener

WASH CYCLE

a) Fill with water - Allow 20 second for the machine to fill with water.

b) Add detergent - Allow 5 seconds to add detergent 5 seconds after the machine has filled with water.

c) Agitate - Allow 60 seconds for agitation.

d) Add bleach - Allow 5 seconds to allow bleach 15 seconds after the machine has started to agitate.

e) Drain water - Allot 10 seconds to drain most of the water from the machine.

f) Spin and drain water - Allow 10 seconds to spin and drain the remaining water from the machine.

g) Fill with water - Allow 20 seconds for the machine to fill with water.

h) Add fabric softener - Allow 5 seconds to add fabric softener 5 seconds after the machine has started to fill with water.

i) Agitate - Allow 30 seconds to agitate.

j) Drain water - Allow 10 seconds to drain most of the water from the machine.

k) Spin and drain water - Allow 10 seconds to spin and drain the remaining water from the machine.

RINSE CYCLE

a) Fill with water - Allow 20 seconds for the machine to fill with water.

b) Agitate - Allow 30 seconds to agitate.

c) Drain water - Allow 10 seconds to drain most of the water from the machine.

d) Spin and drain water - Allow 10 seconds to spin and drain the remaining water from the machine.

Spin Cycle

a) Drain water - Allow 10 seconds to drain most of the water from the machine.

b) Spin and drain water - Allow 10 seconds to spin and drain the remaining water from the machine.

The inputs and outputs of the laundry washing machine are listed as:

Inputs to the PLC		Outputs from the PLC	
0	Hot Wash	0	Hot Water Feed
1	Warm Wash	1	Cold Water Feed
2	Cold Wash	2	Detergent Feed
3	Warm Rinse	3	Bleach Feed
4	Cold Rinse	4	Fabric Softener Feed
5	Wash Cycle	5	Drain
6	Rinse Cycle	6	Agitate
7	Spin Only	7	Spin
8	Add Bleach		
9	Add Fabric Softener		
10	START		
12	RESET		
15	STOP		

In this project the functions of a washing machine are to be controlled by a Programmable Logic Controller (PLC). RS Logix software is used to create the ladder logic for the PLC. The operator is able to select the input by using different switches. The outputs are shown with Lighting Emitting Diodes (LEDs). Another part of the project is to include operator interface into the project. Wonderware software is used to show the control panel and the output panel. These panels are shown on the computer screen. The final part of the project is the model. The model looks like a washing machine. There is a control panel through which the operator can select the desired inputs. Located on the front of the machine are the LEDs which show the outputs.

The BSEMET students worked on the implementation of the laundry washing machine during the Fall 1999 semester. In writing the PLC ladder logic for the laundry washing machine, several steps were taken:

1. A sequential function chart (SFC) was established showing timers. The sequential function chart is shown in Fig. 1.
2. The ladder logic was started beginning with the start and stop of the program.
3. The different inputs and outputs were selected. They are shown in Fig. 2.
4. The entire program was written from the SFC. The program was then tested several times and the final program was completed. The PLC ladder logic functional chart is shown in Fig. 3. The key for the functional chart is shown in Fig. 4.
5. The last item included in the logic was the reset button.

In this project operational interface was incorporated into the function of the prototype. Wonderware software was used to control the interface. The entire control panel and output panel are shown on the computer screen and are fully functional. The operator can make all selections from the screen. Starting and stopping can also be done from the computer. All the outputs are then shown on the screen.

VI. TESTS/RESU.LTS

When the PLC ladder logic was tested, it failed many times and had to be rewritten. The PLC ladder logic was tested using the panel of lights and switches which is located in the Penn State Altoona Lab. Parts of the project were tested separately. First a problem occurred with the outputs being used too many times throughout the logic. This problem was solved by using bits. Another problem was the start/stop part of the program. Latches were used to solve this problem. With so many different timers running it was hard to keep track of what was being timed. After many different rewrites of the original program, the final program worked fine.

VII. SUGGESTIONS FOR IMPROVEMENT

This project could be more advanced in many ways. Something that could be done in the future is that a real washing machine be taken from a junkyard and gutted. A new motor would be the first thing that would have to be added. This is the main reason behind the machines going bad. Next, dispensers would have to be added to allow for mixing bleach, detergent, and fabric softener. The entire panel would have to be removed and reconstructed. A panel of switches can be used like the ones in the prototype in this project. A terminal block would then be used to connect to the PLC. The original water feeds and drain could be still used. This machine would be fully functional and could actually wash clothing. Another thing that can be done is with the operational interface. A picture of the washing machine can show it filling and the water being added. It can also show when bleach, fabric softener, and detergent are being added.

VIII. CONCLUSIONS

Completed design systems are to meet the design specifications and to function properly. The best way to determine this is by putting the system through a testing phase. When this system was completed, it went through a test phase and met all of the specifications stated previously.

Overall, this design project provides a full understanding of how programmable logic controllers operate and how to program them. It provides an understanding of the different methods that can be used to accomplish various tasks while programming the ladder logic.

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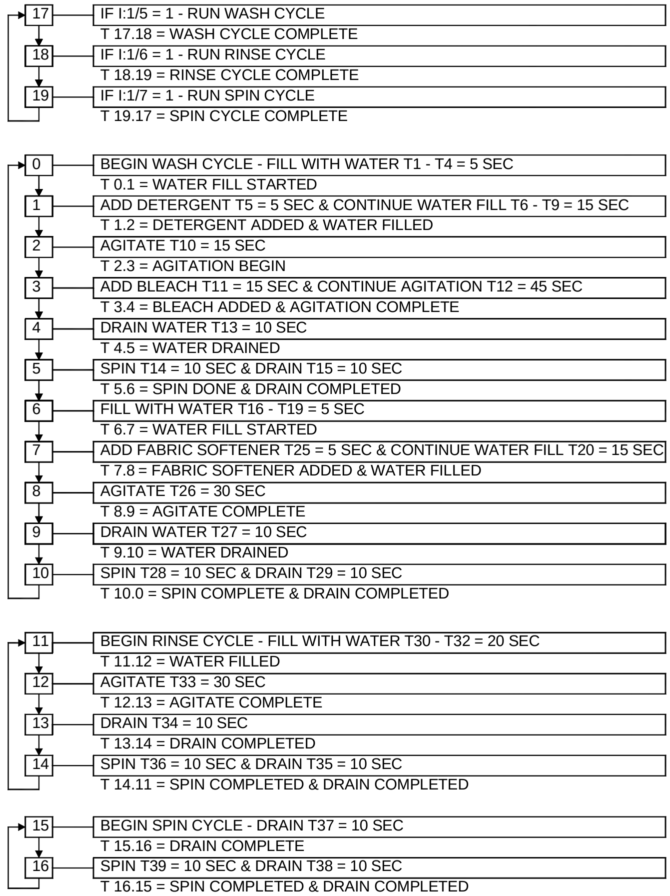

Figure 1: Sequential Function Chart (SFC) for laundry washing machine.

INPUTS	
I:1/0	HOT WATER
I:1/1	WARM WATER
I:1/2	COLD WATER
I:1/3	WARM RINSE
I:1/4	COLD RINSE
I:1/5	WASH CYCLE
I:1/6	RINSE CYCLE
I:1/7	SPIN CYCLE
I:1/8	BLEACH
I:1/9	FABRIC SOFTENER
I:1/10	START
I:1/12	RESET
I:1/15	STOP

OUTPUTS	
O:2/0	HOT WATER FEED
O:2/1	COLD WATER FEED
O:2/2	DETERGENT FEED
O:2/3	BLEACH FEED
O:2/4	FABRIC SOFTENER FEED
O:2/5	DRAIN
O:2/6	AGITATE
O:2/7	SPIN

Figure 2: Inputs and Outputs of Laundry Washing Machine.

BEGIN

MANUAL SELECTION BY OPERATOR

C: NONE

A: 1. SELECT CYCLE (WASH, RINSE, SPIN)
2. SELECT WASH (HOT, WARM, COLD)
3. SELECT RINSE (WARM, COLD)
4. SELECT BLEACH (YES,NO)
5. SELECT FABRIC SOFTENER (YES, NO)

WASH CYCLE

C: I:1/5 = 1

A: 1. T1 = 20
2. T5 = 5
3. T10 = 60
4. I:1/8 = 1, T11 = 5
5. T13 = 10
6. T14 = 10
7. T15 = 10
8. T16 = 20
9. I:1/9 = 1, T25 = 5
10. T26 = 30
11. T27 = 10
12. T28 = 10
13. T29 = 10

RINSE CYCLE

C: I:1/6 = 1

A: 1. T30 = 20
2. T33 = 30
3. T34 = 10
4. T36 = 10
5. T35 = 10

SPIN CYCLE

C: I:1/7 = 1

A: 1. T37 = 10
2. T39 = 10
3. T38 = 10

END

Figure 3: PLC Ladder Logic Functional Chart.

T1 – FILL WATER
T5 – ADD DETERGENT
T10 – AGITATE
T11 – ADD BLEACH
T13 – DRAIN
T14 – SPIN
T15 – DRAIN
T16 – FILL WATER
T25 – ADD FABRIC SOFTENER
T26 – AGITATE
T27 – DRAIN
T28 – SPIN
T29 – DRAIN
T30 – FILL WATER
T33 – AGITATE
T34 – DRAIN
T35 – DRAIN
T36 – SPIN
T37 – DRAIN
T38 – DRAIN
T39 – SPIN

Figure 4: Key for PLC Ladder Logic Functional Chart