Implementation of an Integrated Manufacturing & Controls Laboratory

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Abstract

This project will provide the means to initiate an integrated manufacturing and controls laboratory in the School of Engineering at Western New England College. The laboratory will have a major impact on manufacturing and control courses, and provide a means for developing an interdisciplinary senior laboratory exercise. The objectives of the integrated laboratory are: (1) to provide a laboratory environment where interdisciplinary experiments relating to integrated manufacturing and control can be performed, (2) to provide an opportunity for each of the engineering programs (electrical, industrial, mechanical, and bio) to conduct independent experiments relating to manufacturing and control, (3) to provide for the students necessary experience in the interdisciplinary nature of engineering practice, and (4) to provide a facility for the design, development, testing, and manufacture of plastic products.

Background

American industry is well aware of the necessity for effective teamwork in competitive businesses. Teams have become a common form of organization for activities that range from business planning to product design to work improvement projects. In many cases, these teams must transcend traditional boundaries imposed by departments within companies. Often, a major obstacle to effective teamwork are traditional departmental *walls*, which relate not to physical boundaries, but to cultural boundaries that inhibit effective communication. It is fair to say that companies making effective use of interdepartmental teams have overcome this obstacle. It is also true that these walls are the main barrier preventing many companies from utilizing effective teamwork.

One key use of interdepartmental teams that involves engineers is product design. Here, team members from functions that may include marketing, design, manufacturing and finance (among others) work together. Their work starts early in the design process and extends through the time of full scale production. These teams are known to decrease time-to-market, reduce costs, and improve quality. Terms such as concurrent engineering, simultaneous engineering, and integrated product development have been used to describe the work performed by these product design teams.

Engineering education has been slow to follow this trend. For the most part, students take courses and perform laboratory exercises in their chosen major, with little exposure to other disciplines. They rarely, if ever, work together with students from other disciplines. There are numerous reasons for this phenomenon. On one hand, the scope of required topics has increased dramatically. It is more and more difficult to cover any engineering discipline within the traditional four year window. Hence, curricula are more and more packed with the basic concepts deemed necessary for undergraduate knowledge. The need to satisfy accreditation requirements and conform to professional registration examinations contribute to the problem. On the other hand, departmental *walls* also exist in academia, preventing students from gaining exposure to interdisciplinary teams.

The School of Engineering at Western New England College has recently taken steps to create interdisciplinary opportunities for students while still meeting academic goals[1]. The School, which offers ABET-accredited Bachelor Degree programs in Electrical, Mechanical, and Industrial Engineering, also offers optional programs in manufacturing and Bio Engineering. Two recent examples of interdisciplinary activities include a concurrent engineering laboratory exercise involving electrical and industrial engineering students[2] and a series of manufacturing laboratory exercises that involve mechanical and industrial engineering students[3]. This paper describes the most important extension of this work-the development of an *integrated manufacturing and controls laboratory*, jointly designed and administered by faculty representing the Electrical, Mechanical, and Industrial Engineering departments.

Integrated Manufacturing and Controls Laboratory

The new interdisciplinary laboratory, which consists of a plastics extruder and related control systems hardware and software, was funded by an NSF-sponsored equipment grant. The specific configuration of the laboratory was chosen to create an environment for meaningful interdisciplinary laboratory work as well as improving the laboratory facilities available to each individual department. The configuration also brings plastic technology and the ability to do rapid prototyping of processes into the curricula. Rapid prototyping has been made possible through improvements in manufacturing control system technology, such as fast DSP (digital signal processing) boards and powerful design software packages (e.g. dSPACE and MATLAB). The proposal was developed with the help of engineers and scientists from Monsanto Corporation. These contacts contributed guidance regarding plastic processing and provided perspective on the skills they consider important in young engineers.

Process Equipment

The laboratory is centered around an extrusion system consisting of a ¾ inch extruder, a water trough, and a combination puller/pellitizer. Figure 1 is a schematic diagram of the extruder. The system also includes one additional extruder screw and dies to produce rods and strips. The extrusion process was chosen because it is a safe and affordable process with suitable complexity from a manufacturing and controls viewpoint. For example, several process parameters must be set, including barrel zone temperatures, extruder screw speed, puller speed, and screw compression ratio. The output of the process can be evaluated in two ways. First, process variables that are not directly controlled, such as melt temperature and pressure, can be measured and analyzed. Second, properties of the finished product, such as strength, toughness, and dimensions, can be measured and analyzed. Another advantage of the extrusion process is that control systems can be implemented with minor changes to the equipment.

Injection molding, sonic welding and extrusion were each investigated as candidate processes for the integrated manufacturing and controls laboratory. Injection molding was considered because it is widely used in industry, presents an interesting controls problem and would introduce students to plastic processing technology. Unfortunately, the difficulties in controlling the injection molding process, combined with cost and safety considerations, made injection molding unsuitable for the laboratory. A safer and less costly plastic joining process, sonic welding, was also investigated. However, the simplicity of the process makes the use of sophisticated control algorithms unnecessary.

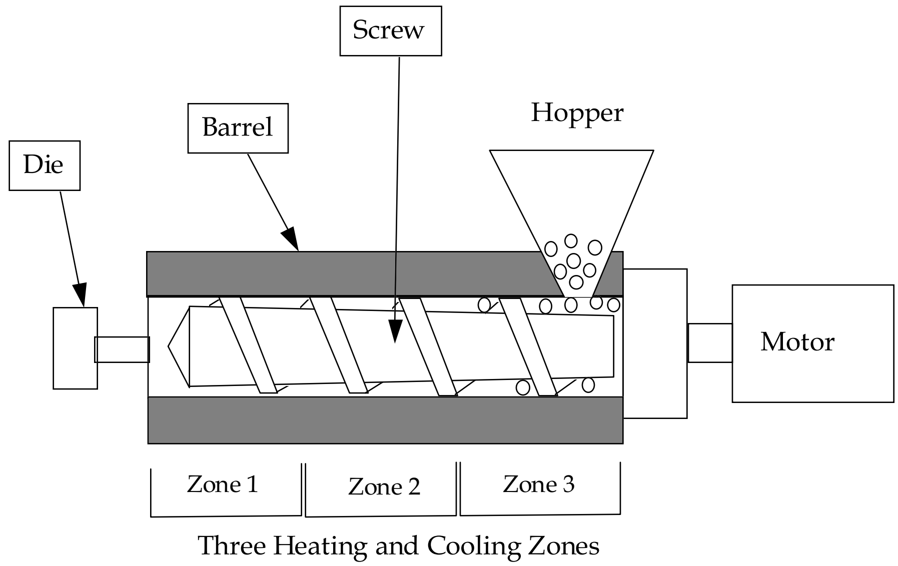

Figure 1: Schematic Diagram of Extruder

Control Equipment

A rapid prototyping facility is an integral part of any successful real-time control assignment because students must be able to finish the project within a reasonable amount of time. The laboratory equipment will allow students to rapidly prototype, implement and test a variety of control algorithms. This will allow design and implementation of controllers using high-level languages, avoiding time-consuming, low-level programming and debugging, and in-depth knowledge of PC-hardware interrupts.

In recent years, system analysis and controller design processes have seen a dramatic increase in computer program usage, in industry as well as academia. One of the more popular computer packages used in this area is MATLAB® by The MathWorks, Inc. MATLAB allows simulation of linear and nonlinear dynamic systems. MathWorks also provides a set of Toolboxes for MATLAB in such areas as signal processing, controls, real-time code generation, etc. In addition, the MATLAB software package is complemented by the SIMULINK™ software which is a front-end to MATLAB for block diagram representation of dynamic systems [4]. Figure 2 is an example of a PID controller using SIMULINK.

Two computers are dedicated to the laboratory. The heart of the control equipment is a DS1102 DSP board by dSPACE and in turn this board is centered around a Texas Instrument TMS320c31 DSP chip. SIMULINK will be used to simulate and design controllers. The final controller design will be ported to a real-time code generator which will generate low-level code for real-time implementation. These programs will then be compiled and linked, and the executable program will be down loaded onto the DSP board for real-time testing. The software packages Cockpit and Trace by dSPACE allow on-line interaction and modification of control algorithm parameters as well as data acquisition and display of sensor signals and control variables running on the DSP board.

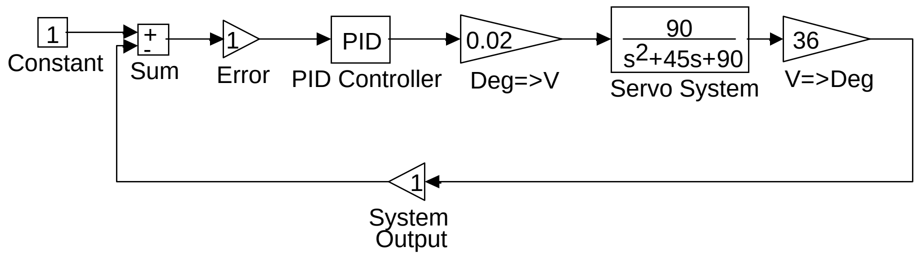

Figure 2: Sample SIMULINK Screen

Laboratory Exercises

At the present time the equipment and software in the laboratory have been assembled; laboratory and class exercises have been developed. Experiments in manufacturing are performed by the industrial and mechanical engineering students and control system experiments are performed by electrical engineering students. An interdisciplinary experiment involving teams of students from the three departments is under development and will be implemented in the Fall 1996 semester. This experiment will make use of the knowledge gained by all students during earlier laboratory exercises. Some of these experiments are described below.

<u>Manufacturing Experiments</u>

A sequence of two exercises is performed by junior-level students in industrial and mechanical engineering. The first exercise begins by introducing the students to the operation of the extrusion process, including safety precautions. Then, the students manufacture strips of polyethylene and measure width and thickness of strips over the course of several minutes. The variation in the dimensions is analyzed using statistical process control methodologies such as control charts and histograms. The students use this information to determine if the process is in statistical control and stable over the course of the production run. If so, control limits are determined for monitoring strip dimensions. Next, the ability of the process to meet specified tolerances on width and thickness is evaluated using process capability analysis methodologies, such as capability indices. Finally, the students are assigned the task of developing a cause-and-effect diagram relating dimensional variation to possible sources of variation.

The goal of the second exercise is to relate controllable process parameters to resulting product characteristics. The basis for the relationship is an empirical mathematical model developed using experimental design methodologies. This model is used as the basis for a setup chart that specifies important process settings necessary to achieve desired product requirements (strength and width of an extruded strap). In this case, the controllable process parameters are die opening and puller speed, with screw speed and operating temperatures held at constant levels. However, the methodology can easily be extended to include these factors. The extrusion process allows for the incremental development of the model in five steps: (1) the material flow rate is determined through testing at various puller speeds to confirm that the flow rate constant and in control, (2) a two-level factorial experimental design is used to develop a first-order model, (3) tests of the model are performed and shows violation of the first-order assumption, (4) a central composite experimental design is used to develop a second-order model, (5) the model is tested and its usefulness is confirmed. The students then use the model to develop the setup chart which indicates the puller speed and die opening that will produce a given strength and width strap.

Controls Experiments

The extruder system has three zone temperatures, one die temperature and screw speed adjustments as shown in Figure 1. This system has been modified to allow implementation of an user-developed control algorithm in addition to existing factory controllers. For example, students can design and implement a control system to produce a uniform strand of material from the extruder. The system will control the temperature of the extruder zones and the speed of the extruder screw. Each activity will be tailored to cover the material emphasized in the controls courses. For instance, design and implementation of PID and lead-lag controllers will be investigated in the Control Systems course. Also, real-time implementation of digital state feedback controllers will be investigated in the Linear Systems Theory and the Computer Controlled Systems courses. In addition, design and implementation of neural network and fuzzy logic controllers will be investigated in the two newly developed courses.

Interdisciplinary Exercise

A significant portion of the senior laboratory courses (6-12 hours) in Electrical, Mechanical and Industrial Engineering will be devoted to an interdisciplinary project. This activity will take place during the first semester of the senior year and will build upon concepts learned in prior laboratory exercises. Interdisciplinary student teams will be presented with an open-ended design/manufacturing problem. A simple product, such as packaging straps, will be designed and manufactured to meet customer requirements. These customer requirements will be stated in terms of product quality, product cost, and the ability to recycle the product. The students will be required to: (1) determine target values for important product attributes and set tolerances on those attributes, (2) determine preferred material(s) and extrusion screw configuration, (3) determine target values for important process parameters, (4) design and implement an economical control system, and (5) explain and quantify the effect of each engineering discipline on the project. This methodology ensures that the activity will be open-ended, challenging, and necessitate cooperation among students from different disciplines.

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