Take the Opportunity to Utilize Design and Construction of Research Devices for Classroom Examples

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Abstract

Research, by its very nature, often involves development of equipment that is new or different from past practice, and significant effort is often required in the development process. As equipment is developed, a minor amount of additional design effort and construction cost can provide significant enduring benefits for undergraduate education, especially in the context of system design. A bi-axial testing machine was developed at Penn State Erie - The Behrend College, as part of a grant, and this paper presents features from the design and construction of that machine that were included to add value to education at Behrend. The bi-axial machine has been constructed, and is being used in both NSF-funded faculty research and undergraduate research, but is also being used as a teaching tool in undergraduate classes such as machine design and measurement and instrumentation. The design documents have been used as an example of the effort to complete a design and to show a proper design process, machine safety features have been demonstrated, and power transmission equipment has been shown to students who have never seen such equipment. The educational results to date are described in this paper, along with some observations on the uses of this machine that have best communicated to students.

Introduction

Mills et al, in 2003, studied the difference between the approaches of problem based learning and project based learning in engineering curriculums. They concluded that project based learning would be more readily accepted into universities and that it would better prepare undergraduate engineers for their futures in industry [1]. The University of Colorado implemented an integrated teaching and learning program (ITL) in an attempt to introduce project based learning into their engineering program [2]. The ITL uses a facility that allows students to work on hands-on design projects along side of class work. Lawrence has concluded that the ITL increases students excitement toward learning, by offering hands-on experience to supplement class room based learning. To add project based learning to their programs a few other schools such as Penn State University Park have added Learning Factories to their campuses [3]. These learning factories also offer opportunities for students to gain hands-on experience in order to promote learning and allow the students to gain a better grasp on theoretical concepts taught in the class room [4]. These types of programs require a large amount of capital to implement; however, there are less costly alternatives that may produce similar results.

Teaching and research compete for the time of a faculty member, and there is a distinct advantage when a single effort can be utilized to further both. Traditionally, the most direct way in which this is accomplished has been using graduate or undergraduate students to do some of the efforts required to complete research projects, giving the faculty member the benefit of helping hands and the student the benefit of research experience. Yet this approach assumes that any equipment required for the research is already complete and in place. The predominant experience of the first author is with materials testing, where either the testing method or the test machinery is not standard. Particularly in a situation where machinery is specially designed and constructed for a research project, there is an opportunity to add features to the design that will permit the finished piece of research equipment to be utilized as an enduring classroom example in ways it otherwise might not be usable.

Stereotypically, engineering students are abstract thinkers, comfortable starting with math and theory, doing computations based on the math and theory, and building their understanding of specific systems from their understanding of the theory. In contrast, there are other students who are concrete thinkers, much preferring to start with an example of a real system, and building to the general principle using an example as a foundation from which to build. Arguably, in the current student population, neither group is particularly mechanically knowledgeable, and the technology of recent years has not helped. As an example, automobiles have gotten more complex and harder to work on, which discourages interest, while at the same time becoming more reliable which reduces the need to be interested. In the context of a machine design course, shafts, gears, belts, bearings and motors are almost completely unknown to many students. Research equipment is one available avenue for examples of these and other subsystems that can be used in the classroom environment. In addition, most students have not designed anything, or if they are a tinker and have designed something they have not used an organized design process and documented the design decisions. The biaxial machine described in this paper offers both a way of teaching a proper design process and demonstrating machine design concepts in a working environment.

Bi-Axial Test Machine in Context

A faculty member at Penn State – Behrend received a National Science Foundation (NSF) grant to build a test machine and do some bi-axial material testing with the goal of developing more complete material characterization for a few specific light metals. The results would have particular application to the forming of aluminum or magnesium sheet for vehicle components. Sheet forming and stamping operations often strain the sheet in two directions, yet most available material data is unidirectional, and when the sheet is produced, the rolling process makes the material anisotropic. Material characterization based on bi-axial testing is expected to improve the ability of manufacturers to predict the behavior of metals during forming.

For the NSF grant, the machine was specified to have a capacity of 50kN in each axis. A furnace is part of the overall system, so that material tests may be performed at temperatures up to 750°C. At elevated temperatures, the strain to failure of the specimens is expected to be large, so the machine was designed to have a grip travel of approximately 250 mm on each side of center of the machine, for a total of 500 mm for each axis. Before the design progressed beyond the concept stage, it was clear that the final location of the machine was uncertain; hence an additional design requirement was that the machine must be movable by pallet jack and fit through existing laboratory doors without much disassembly. The resulting machine has an open frame, and each axis is mechanically synchronized and driven by a single motor. The power transmission components are almost entirely hidden within the tubular steel frame to keep extraneous objects such as fingers out of the mechanism. The completed machine, without the furnace mounted, is shown in Figure 1. To give the viewer a better understanding of the magnitude of the machine, note that the top of the upper frame member is 2340 mm above the floor.

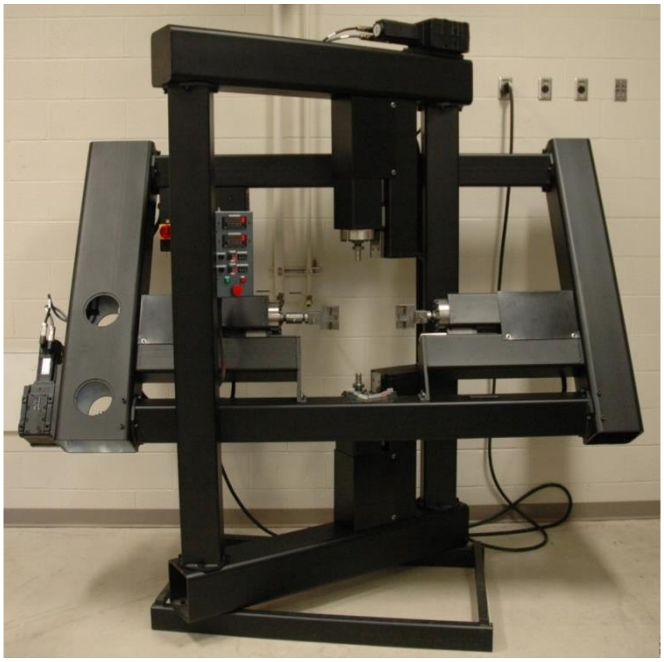

Figure 1: Bi-Axial Test Machine

During design and construction of the machine, student assistance was utilized. Undergraduates did the solid modeling and the majority of production of shop drawings from which the machine was built, and other undergraduates have done the initial research testing using the machine. Since engineering at Penn State – Behrend is practically undergraduate-only at this time; thus far there has been no graduate student participation in bi-axial design or testing. Involvement in design of the machine and in ongoing research is of value to the students involved, but little endures from these efforts that will benefit students not directly involved on an ongoing basis.

Design Phase Examples

During the design phase of this test machine, the project was slightly expanded with the goal of enhancing the machine to allow it to be classroom examples on an ongoing basis. As is typically taught in design courses, a ‘clean sheet’ design requires the functions and design requirements (or specifications) to be established, followed by the development and evaluation of alternatives. Capturing this process is not costly; arguably, ***not*** capturing what is developed in this process is likely to be very costly. Good results are often correlated with good design process and good documentation. The design package for this machine is a well-documented example of the design process ready to be taken to class or used as a case study in design.

One of the mistakes of neophyte designers is to take their first concept and try to make it work. Good design requires many alternatives, and consideration of the advantages and disadvantages of each [5], where possible combining the best features from each alternative to make a combined version better than any one alternative by itself. In the design of this machine, a search for commercial machines was performed, and patents were searched for existing concepts for bi-axial test machines. Home-grown alternatives were considered as well, and the final design was selected from the alternatives identified. Documentation of this effort, and a final result that does not look like any of the other machines is valuable as an example of the ideation process. One feature of the machine that is clearly different about the Penn State – Behrend machine is that there are separate frames for vertical and horizontal axes, and the two frames are not in the same plane. Geometrically, the structure of this bi-axial machine has caused some 3-dimensional thinking in the students that have contemplated the result.

Similarly, the detailed design of the various parts with computations and sketches, and the stackup sketches for detailed geometric design are all documented and can be used as an example is design courses. The calculations and geometry are required for the complete design, as is selection of drive components and fasteners, but by a little additional effort these were recorded and organized in a way that has instructional value. A solid model including the majority of the detail parts, and all of the detailed shop drawings necessary for manufacture were produced at Behrend, and are not divorced from the design and detailed calculations. Students in graphics classes certainly learn how to make solid models, but graphics class assignments do not generally follow from a calculation package. Likewise, design projects in machine design courses often result in solid models, but the details get left out of the model because the focus of the course is design and analysis not detailed solid modeling. Here is the entire package, with both the design details and resulting solid model and detailed drawings; the whole process package that students are supposed to be able to do but rarely get to see complete, and we have the physical machine available for comparison. With a complete package, the context is demonstrated, rather than just one piece of the engineering enterprise at a time.

In the particular case of the bi-axial test machine, a scale model, Figure 2, was constructed prior to the actual machine. Rapid prototyping technology has greatly advanced over the past 30 years, allowing outstanding models to be built, and the models can have great utility during the design process. Here the model was built of wood, and not precisely to scale in all areas, but with the goal of testing the assembly and joining sequence of the full sized machine. Before the model was complete, it became obvious that the size and weight of the machine components would prevent machining after welding of subassemblies. The industrial experience of the first author was in the ‘big steel’ arena of central power station equipment, where the machine tools and manufacturing methods would easily handle 1000kg parts with dimension of several meters. Such methods are not available at Penn State – Behrend, and assembly of the model demonstrated that changing the design was essential for manufacture and assembly. This is a valuable example of design for manufacture and assembly, and is readily comprehended when the model is compared to the full size machine.

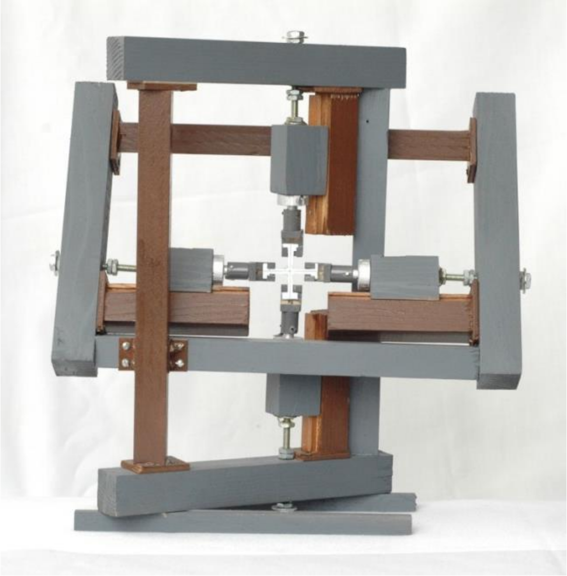

Figure 2: Scale Model of Test Machine

Enduring Examples in an Operating Machine

The bi-axial machine frame was built out of rectangular tubing because it is strong enough to carry the load, and stiff enough that the deformation of the machine under load is acceptably small. Given a machine frame that is hollow, the next idea was to put the power transmission equipment inside the tubing as much as possible to keep the moving parts separate from contaminants, whether dirt or fingers. Body parts and fluids are quite corrosive to machinery, but machinery is even harder on the body parts. The bi-axial machine was designed here, so is a more personalized example, but safety guarding and protection of machinery is essential for students to comprehend, and this is a good example. Many electric drive universal test machines have the same safety features and would be equally good examples, but only if safety is discussed in the context of the particular machine. Just existing does not make a useful example; discussion is essential.

Likewise, Penn State – Behrend's machine is not of infinite size or load capacity, so both travel limit switches and force overload shut offs have been included in the control system for the machine. Students in machine design classes should be taught principles of safety; this machine is an enduring example of the sorts of considerations that must be taken to protect both user and machine. But because the machine was designed and built at Behrend, the wiring diagrams for the control system are readily available for instructional purposes. The machine can be set to run and allowed to 'limit out' at the end of travel without damaging the machine, yet the controls allow the axis to be reversed and returned. A demonstration of the machine, coupled with a brief explanation of the safety systems, seems to communicate to students much better than trying to explain the same concepts in a classroom setting without the demonstration.

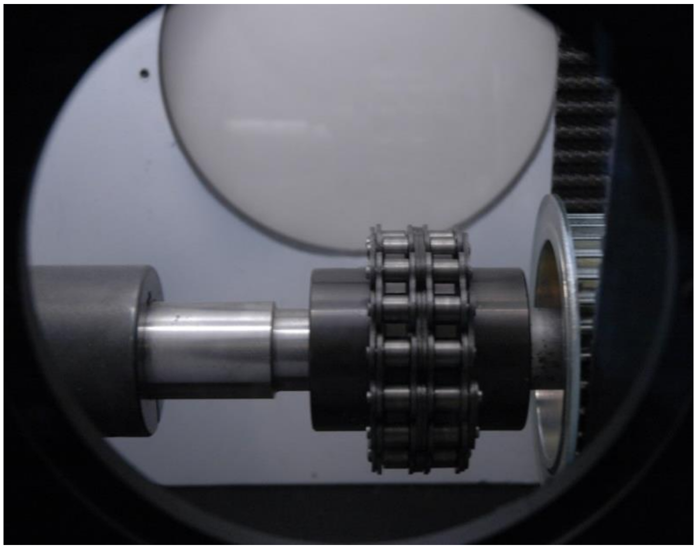

Figure 3: View Through Window in Left-hand Frame Tube

A pair of windows were machined in the left-most frame member of the bi-axial machine. Visible through those windows are the shaft from the gear reducer, a stub shaft, a timing belt drive from the reducer to the left side lead screw, the end of the drive shaft across the machine to the right side lead screw, a mounted bearing, and two different shaft couplings, some of which is shown in Figure 3. Most students are not familiar with these components and yet we lecture about them and expect the students to do computations to select such parts. Windows into the structure, and a slightly heavier structural member to support the load with windows cut out were a few hundred dollars extra, but it is a tremendous opportunity for concrete thinking students to benefit by safely observing a power transmission system in operation. Photographs are good, but understanding of size is easier when seen in person. The drive motors and gear reducers are on the outside of the structure and readily visible to students and hence communicate the physical size of the motors, yet the output is inside the structure for safety.

Finally, in measurement and instrumentation courses, students are taught that there are analogous signals. But how do they appear in operating systems? For this machine, the loadcells were purchased specifically. The output of the loadcell for a given tension or compression load is given on the manufacturer's data sheet for each loadcell. The displays, which include the required power supply and signal conditioning, likewise take the signal from the loadcell and amplify it so it has another magnitude. Because we constructed the machine, we have access to the voltages and can demonstrate that a load of 1,000 pounds the output of the loadcell is 2mV with the standard 10V excitation, and the output of the display is 1V. Likewise at 2,000 pounds the loadcell output is 4mV and the output from the display is 2V. We measure and record voltages, but what is understood are the physical parameters for which the voltages substitute.

Conclusion

Most faculty members and their academic institutions have a dual mandate, both to teach and to do research. It is our contention that purpose-built research equipment can and should be designed and constructed so that the internals are accessible to be used as examples in undergraduate education. Not every detail is appropriate for student access, so some judgment is required in what is open for student modification, but demonstrations of what is present and explanation of why and how it was designed offer an outstanding opportunity to solidify the understanding of students.

Bibliography

[1] Mills, J. E., & Treagust, D. F. (2003). Engineering education—Is problem-based or project-based learning the answer?. *Australasian Journal of Engineering Education*, *3*, 2-16.

[2] Carlson, L. E., & Sullivan, J. F. (1999). Hands-on engineering: learning by doing in the integrated teaching and learning program. *International Journal of Engineering Education*, *15*(1), 20-31.

[3] Lamancusa, J. S., Jorgensen, J. E., & Zayas-Castro, J. L. (1997). The learning factory—A new approach to integrating design and manufacturing into the engineering curriculum. *Journal of Engineering Education*, *86*(2), 103-112.

[4] Hadim, H. A., & Esche, S. K. (2002). Enhancing the engineering curriculum through project-based learning. In *Frontiers in Education, 2002. FIE 2002. 32nd Annual* (Vol. 2, pp. F3F-1). IEEE.

[5] R. Budynas and K. Nisbett, Shigley's Mechanical Engineering Design, 9th edition, New York: McGraw-Hill, 2011.