Multi-course design project creates ties between various mechanical engineering topics

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Introduction

In a typical undergraduate mechanical engineering curriculum, students take a wide variety of engineering courses from the basic categories of design, analysis, and laboratory, for example strength of materials, mechanical design, manufacturing, thermo-fluids and instrumentation among others. All too often, students compartmentalize their courses, failing to see the relationship between topics taught in different courses. In an effort to reduce this compartmentalization and increase overall knowledge and skill integration, a multi-course project was developed. The project requires the students to design, analyze, manufacture, instrument, and evaluate a load cell. The courses directly involved in the project are Mechanical Design, Manufacturing, and Instrumentation, although many other courses were indirectly involved. These three courses are taken concurrently during the first semester of the junior year. Working in groups of two or three, students perform different aspects of the project in each course over a four-week period. In addition to fundamental design and analysis methods, several engineering software packages are integrated into the design and analysis of the load cell including Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), finite element analysis (FEA), and digital data acquisition system. The current version of the project has gone through two cycles with outstanding results. All of the student groups were successful in completing the project. The student reaction to the project was positive and they indicated that the project caused them to see the ties between the three courses that otherwise would have been somewhat disconnected. This paper discusses the project philosophy, the load cell design, the integration of course topics, and the specific design, analysis, and software techniques necessary to create the project. In addition, student reactions and experiences are presented and strategies for expanding the project to other courses are discussed.

Educational Philosophy and Background

Courses in most mechanical engineering curriculums can be loosely grouped into design, analysis, and laboratory type courses. Within each of these categories, courses are configured based upon subject matter. While this model is efficient for instructional purposes and for student learning of specific information, it can lead to compartmentalization of information and engineering functions as discussed earlier. Therefore, an important objective of the Mechanical Engineering Department at Lafayette College is to create activities that break down the barriers between course topics, and the engineering functions of design, analysis, and manufacturing.

By the junior year of the mechanical curriculum at Lafayette College, the students have completed their math, science, and engineering science sequences. They also have had courses in engineering design and manufacturing. At this time, the students begin to take the core of their mechanical engineering courses. Therefore, by this time, the Department believes the students have sufficient background to handle a major cross-course project with analysis, design, and manufacturing content. Also, it is believed that it is still early enough in the curriculum to help minimize future course and subject compartmentalization.

The multi-course project is the design, analysis, manufacture, and evaluation of a load cell. The project was created to pull together diverse subject matter both directly and indirectly from several past and concurrent courses. It involves the fundamental engineering functions of analysis, design, and manufacture. It also couples traditional design and analysis techniques with modern software, manufacturing, and data acquisition tools.

Description of Load Cell and Theory of Operation

The load cell is shown schematically in Figure 1. As can be seen in the figure, a relatively large binocular shape hole goes through the center of the unit and strain gauges are placed at the four thin cross sections. When the external force, F, is applied to the load cell, the thin cross sections deform thereby causing a proportional change in the output voltage of the strain gauges. The exact shape of the binocular cutout is designed by the students and has a major influence on the sensitivity and capacity of the load cell. The load cells are constructed of 6061-T6 aluminum although any suitable engineering material could be used. To simplify construction, all of the student groups are required to design their load cells within a ½" x 1 ½" x 6" bar of material.

The binocular beam load cell is quite interesting in that the output is not effected by the point of application of the external force so long as the force is not directly above the cutout. In other words, as long as the external force, F, in Figure 1 is over the solid portion of the load cell, the output will be directly proportional to the load and not be affected by distance L.

The binocular beam load cell actuates similar to a parallelogram four-bar mechanism. The four thin cross sections where the strain gauges are attached behave like revolute joints, and the top, bottom, left and right sections of material act like rigid links. As the external load is applied to the right hand "link" with the left hand link grounded, the load cell is "actuated" with each set of opposing sides moving in a parallel fashion. This in turn causes a strain on the "joints" which changes the output of the strain gauge. An example of this type of deformation is shown in a finite element simulation in Figure 2.

Implementation in courses

The load cell project is directly implemented into three courses; Instrumentation, Engineering Design I, and Manufacturing and Design. Along with their basic subject matter, these courses cover three major functions of an engineer, design, analysis, and manufacturing. Therefore, the project not only integrates course subject matter, but major engineering functions as well. The project also mixes traditional design and analysis techniques with modern software, computer, and manufacturing tools in designing, analyzing, manufacturing and finally testing the load cells. Successful execution of the project requires a highly coordinated effort by the instructors and students in the three courses. In this section, each step of the project will be described along with the hardware and software tools required for the various steps.

To begin, the binocular beam load cell project is introduced to the student teams in their Instrumentation Laboratory course. The primary goals and constraints of the project are described including load cell performance criteria and dimensional limitations of their designs. The multi-course aspect is also explained at this time.

The first step of the project is to introduce the students to the TransCalc software package from Measurements Group [1]. This commercially available software package was written so that manufacturers of load cells could quickly design various types of load cells, including the binocular beam type. The software prompts the user for the dimensions and material properties of the load cell and strain gauges. The software uses closed form and empirically developed solutions to determine if the design is valid, i.e., if the sensitivity, strain magnitude and strain variation are at acceptable levels. Once a satisfactory design has been completed, the TransCalc software displays the output of the load cell in millivolts of output per volt of input excitation at the design load.

Even at this early stage in the design process, students consider aspects of design that they normally would not have to consider in a “paper” design. For example, by making the cross section of material just beneath the strain gauge thinner, the students can increase the sensitivity of the load cell, however, there is a practical limit as to how small one can machine the cross section with a milling machine. This gives the students an excellent experience in conflicting goals in design. From a manufacturing standpoint, thicker cross section is better, but, from a performance standpoint thinner is better. This forces the students to make design decisions that clearly impact the manufacturability and ultimate performance of their project.

Once students have their load cell designed, they validate it in their Engineering Design course using the ANSYS [2] general-purpose Finite Element Analysis (FEA) software package. The students model the load cell using two-dimensional elements and have to determine and apply the appropriate boundary conditions and loads. It is at this point that the *students* realize that the placement of the load does not affect the deformation of the load cell. The graphical results of the finite element solution are absolutely critical in helping the students to visualize the four bar linkage behavior of the system.

Upon completion of the finite element model, students compare the horizontal strain at the strain gauge locations to that predicted by the TransCalc software. The students are required to explain why the two modeling techniques have slightly different solutions. Additionally, the students are required to use ANSYS to generate a contour plot of the strain in the horizontal direction for the entire load cell and make remarks and conclusions as to its features.

The next step in the project is to manufacture the load cell using a Computer Numeric Controlled (CNC) milling center, but before this can be done the students have to write the G-code program for the CNC machine. Instead of writing the G-code software manually, the

Virtual Gibbs Computer Aided Manufacturing (CAM) software package by Gibbs and Associates [5] is utilized. The students first draw their load cells in AutoCAD [4] and import the CAD geometry into the CAM software system. Using the CAD geometry, the students generate the tool path to machine the binocular shape out of the aluminum bar. But before actually cutting the aluminum material, the tool path is validated using the animation feature in the Gibbs software package. It is at this point that the students get a sense of the power of the hardware and software tools that they are using to design and manufacture their projects. The animation enables them to "virtually" see their part being machined on the computer screen, which proves to be quite enlightening to the students.

Once the students have their toolpaths completed, it is time to actually cut the load cells from the bars. As mentioned earlier, all of the student groups use ½" x 1 ½" x 6" aluminum bars. This is done so that all of load cells can be held with a 6-inch standard machine vise on the table of the CNC machine. Additionally, and probably more importantly, all groups are required to use the same size material because they are required to use the same point on the piece as the origin. This is done to eliminate the need to reset the part origin between student groups thereby reducing the possibility of crashing the CNC machine. The location of the origin is checked both in the CAM software and at the CNC machine prior to cutting the load cell. We have found that each load cell only takes approximately 3 minutes to machine in the CNC machine and only about 3 minutes to setup, therefore we can machine approximately 10 projects per hour. After the part is completed on the CNC machine, the students drill two holes through the edge of the piece. One of these holes is to clamp the piece and the other is to attach a hook for the load.

In the final process of the project, the student groups are required to instrument and test their load cells. Strain gauges are attached to the project using the techniques previously learned in the class. The student groups are also required to use a PC based data acquisition system running HP Vee by Hewlett Packard [5] to calibrate their load cells. Using the results obtained from the data acquisition system and the TransCalc software, students make conclusions as to the accuracy, sensitivity, capacity and calibration constants of their load cells.

Scheduling and Grading

Although this project is fairly elaborate in that several courses are involved and many pieces of hardware and software are used, the management is simplified by dividing the project into four discrete steps each taking one week to complete. The flow of the project and a description of each task can be seen in Table 1. One should note that this multi-course project was not developed to teach the skills and techniques used to create the load cell, but as an exercise in using them on a real product.

The grading of this project is complicated since it involves different courses and instructors. Furthermore, in a typical semester there are always students, who for one reason or another, are not simultaneously enrolled in all three courses. Because of these reasons, the grading of each project topic is independent to the other topics and no final report summarizing the entire project is required. This grading technique has advantages for the instructors and students. One advantage is that instructors of different courses do not have to collaborate to determine student grades in their respective courses. The separate grading and reporting also works out nicely for students not simultaneously enrolled in all courses. The key is to be sure that each group has at least one representative in each course thereby ensuring completion of the project.

Summary and Recommendations

The load cell project was developed as a solution to the problem of students' compartmentalizing course subject matter. The result is an activity, which not only integrates subject matter from different courses, but also the major engineering functions of design, analysis, and manufacturing. Basic analysis and design methods are supplemented with modern computer, software, and manufacturing tools to create and evaluate the load cell. Along with integrating across courses and major engineering functions, the project also serves as a small-scale design and build capstone experience. Implementation of the project requires a coordinated effort from the instructors and students, monetary support from the Department, and engineering shop support from the Engineering Division.

The project appears to be meeting its goals. Student satisfaction with the project is high, and project assessment indicates that the integration of subject matter and engineering functions is successful. Based upon the success of the load cell project and the importance of integrating subject matter across courses, the Department will attempt to develop more of these types of projects.

References

1 TransCalc, Version 1.11, Measurements Group, Inc., Raleigh, NC, (1997).

2 ANSYS, Version 5.7, ANSYS Inc., Canonsburg, PA, (2000).

3 Virtual Gibbs, Version 5.16, Gibbs and Associates, Moorpark, CA (2000).

4 AutoCAD 2000, Autodesk, Inc., Alameda, CA, (2000).

5 HP VEE, Version 5.0, Hewlett-Packard Co., Santa Clarita, CA, (1998).

Figures

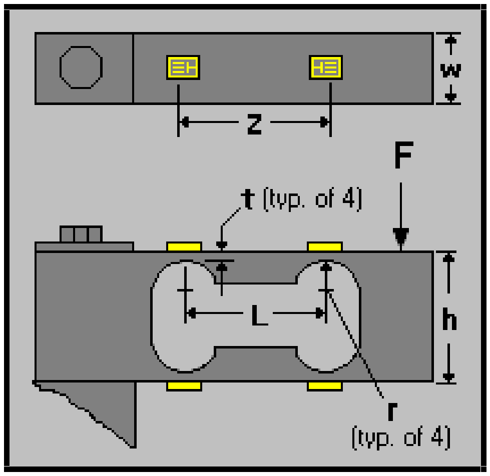

Figure 1 Schematic drawing of binocular type load cell

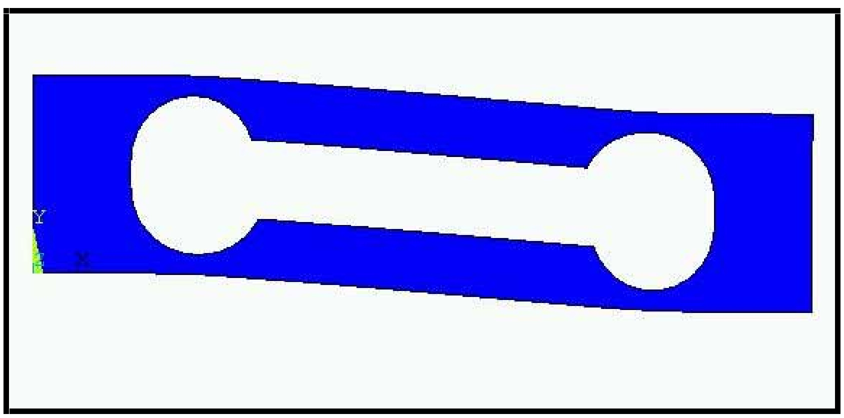

Figure 2 Finite element simulation of magnified deformation

Tables

Table 1

Week	Course Title	Description of task to be performed	Hardware / Software used
1	Instrumentation Lab	Design load cell	TransCalc
2	Engineering Design	FEA of load cell	ANSYS
3	Manufacturing & Design Lab	Generate tool path	AutoCAD & Virtual Gibbs, CNC Milling Center
4	Instrumentation Lab	Instrument & test	HP Vee