THE COMPRESSOR PROJECT: COUPLING THERMODYNAMICS AND MECHANICAL DESIGN IN A CROSS-CURRICULAR PROJECT

Eric W. Constans[1], Hampton C. Gabler[1]

Abstract *¾ This paper describes a design-based effort to build an effective cross-curricular link between Thermodynamics and Mechanical Design -- two traditionally distinct subjects. The result was a design challenge in which the authors asked their junior engineering undergraduate students to design and build an air compressor as a project conducted simultaneously in their Thermodynamics and Mechanical Design Courses. This paper describes the design challenge, the results of this cross-curricular experiment, and future enhancements to the project.*

Index Terms ¾ Interdisciplinary projects, Mechanical Design, Thermodynamic Design

BACKGROUND

Traditionally, Thermodynamics and Mechanism Design are taught as two completely distinct engineering subjects. The courses use different methods of analysis, rely on different computational tools, and are rarely taught by the same faculty members. It is not surprising, then, that students leave these courses with the impression that the two subjects are independent and perhaps even disjoint areas of mechanical engineering.

Thermodynamics is a highly conceptual subject. While a Thermodynamics Laboratory often supplements this course, the subject is rarely taught using design-based projects. Mechanical Design and Synthesis focuses on the design of mechanisms. Students in Mechanical Design are required to complete a design project to reinforce the concepts taught in the course. At Rowan University, the Thermodynamics course has always been presented by a member of the Thermal Systems stem of the Mechanical Engineering Department while the Mechanical Design and Synthesis course has always been presented by the Mechanical Sy stems stem of the Department.

Our concern was that the format of these courses leaves the student with the unfortunate impression that these subjects are totally distinct and unrelated. The traditional methods of teaching both subjects ignore the fact that mechanical systems, e.g. gas turbines, reciprocating engines, and compressors, frequently require the design, analysis, and careful integration of subsystems that have both thermodynamic and mechanical system design specifications.

The project described in this paper began as a collaborative effort between the two authors – one teaching Thermodynamics and the other teaching Mechanical Design and Synthesis to the same group of students – to seek common educational ground in our respective course presentations. The result was a design challenge in which we asked our students to design and build an air compressor as a project conducted simultaneously in their Thermodynamics and Mechanical Design Courses.

Thermodynamics and Mechanical Design are both required Junior-level courses at Rowan University. A total of twenty-one students were involved in the project.

GOALS

Our objective for the students was to design and build a compressor. Our educational objective was to explore whether we could build an effective cross-curriculur link between Thermodynamics and Mechanical Design -- two traditionally distinct subjects.

SCHEDULE

The project was assigned in the fourth week of a 15 week semester. The thermodynamic analysis was due after one week. A complete motion analysis, including position, velocity and acceleration of the mechanism was due after two weeks. Demonstration of the completed device and final reports were required three weeks after the project was assigned.

Students worked in teams of four on the project. They had access to modern engineering software tools including AutoCAD, Matlab, Working Model 2D and Excel.

EDUCATIONAL GOALS

Students needed to understand the following topics in order to complete the compressor project successfully.

Thermodynamics
(a) Control mass: energy balance analysis
(b) Isentropic compression of an ideal gas
(c) Introduction to non-reacting thermodynamic cycles

Mechanical Design and Synthesis
(a) Design of a Linkage to Perform a Specific Task
(b) Motion Analysis: Position, Velocity and Acceleration of a Linkage

[1] College of Engineering, Rowan University, 201 Mullica Hill Road, Glassboro, NJ 08028

(c) Force Analysis: Calculating Required Motor Torque and Pin Forces

Prototyping Skills
(a) Transfer of theoretical design into physical design
(b) Fabrication of compressor parts in the Rowan Machine Shop
(c) Design testing / evaluation / improvement

Problem statements for both parts of the project are shown in Appendices A and B.

IMPEDIMENTS

The authors faced several challenges in completing this project. The largest by far was the students' inexperience in prototype fabrication. During the course of the project, students were taught enough machining skills (milling, turning, etc.) to build their prototypes, while simultaneously learning the engineering skills needed to develop a design. However, the lack of experience in mechanical design and fabrication was turned to the instructors' advantage: design concepts taught in the classroom could be immediately reinforced and enhanced in the machine shop.

RESULTS OF PROJECT

A photograph of one student team with their completed project is shown in Figure 1. Figure 2 shows a detailed view of the parts used in building the compressor. All parts, save the motor, batteries and fasteners were made by the students. Figure 3 shows a typical AutoCAD drawing submitted by a student team at the end of the project.

At the completion of the project the compressors were evaluated against one another in a competition. Two criteria were used for evaluation: volumetric flow rate and maximum compression. For the first, the compressors were used to inflate balloons; the compressor that burst its balloon the fastest was deemed the winner. For the second, the compressors were fitted to a tank and compression was measured using a pressure gauge. The authors found that the competition between teams significantly increased the students' enthusiasm and improved the overall quality of the designs and prototypes.

On the whole, the project was deemed a success, both by students and the authors. The students gained a great deal of practical design experience and the confidence that comes with designing and building a functioning device. A

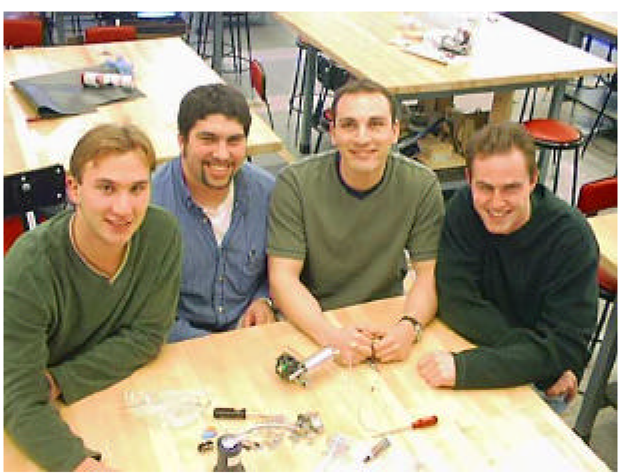

FIGURE 1
STUDENT TEAM WITH COMPRESSOR

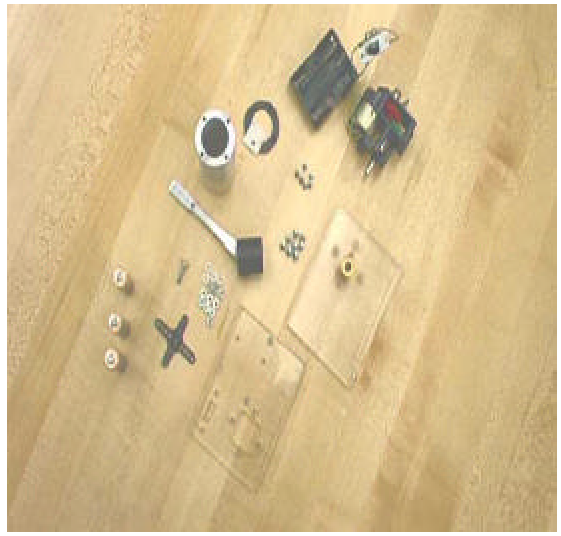

FIGURE 2
COMPRESSOR PARTS

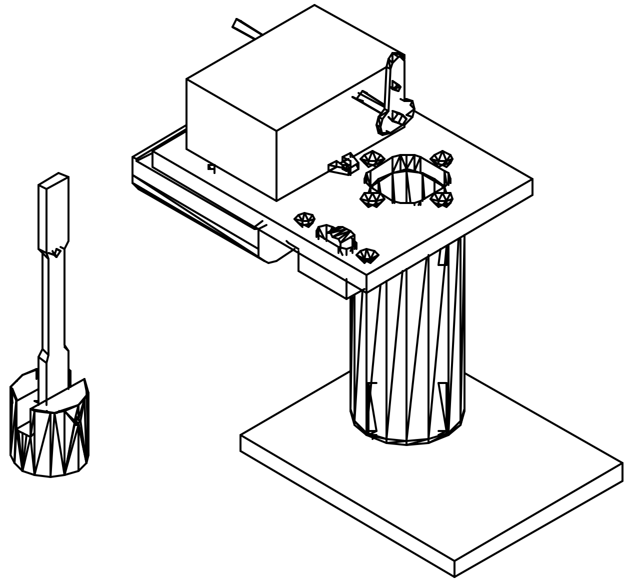

FIGURE 3
CAD DRAWING SUBMITTED BY STUDENT TEAM

similar project, using collaboration between Fluid Mechanics and Machine Design courses, is planned for future semesters.

CONCLUSIONS

The design project described in this paper began as an effort between the two authors – one teaching Thermodynamics and the other teaching Mechanical Design to the same group of students – to seek common educational ground in their respective course presentations. The result was a design challenge in which the authors asked their junior engineering undergraduate students to design and build an air compressor as a project conducted simultaneously in their Thermodynamics and Mechanical Design Courses. Within only three weeks from project assignment, the students had designed, fabricated, and successfully tested their air compressors in a final course competition. The success of this project has demonstrated the feasibility of establishing cross-curricular links between engineering subjects of engineering disciplines as diverse as Thermodynamics and Mechanical Design.

APPENDIX A: THERMODYNAMICS PROBLEM STATEMENT

A reciprocating piston-cylinder system has a piston diameter of D. The piston is attached to a slider-crank mechanism with crank of length *l*. The gap between the top of the cylinder and the piston when the piston is at the top of it's travel (Top Dead Center or TDC) is *x*. The piston-cylinder should be assumed to be an adiabatic, closed system. You might recall that the work done on an adiabatic closed system is a polytropic process where PV^k=constant where $k=c_p/c_v$. Assume air to be an ideal gas.

If the cylinder pressure is 1 atmosphere (14.7 psia) when the piston is midway between the top of its extent of travel (TDC) and the bottom of its extent of travel (BDC), find:

a) Final pressure when the piston at TDC in terms of *l* and *x*. Compute *x* for a system in which D=1", l=1", and P_{TDC} = 3 atmospheres.

b) The Work which must be done on the system to compress the air from BDC to TDC in terms of *l*, *x*, and *D*. Compute the work in ft-lbf for a system in which D=1", l=1", and P_{TDC} = 3 atmospheres.

c) Find the force exerted on the Piston face (and hence the piston-slider pin connection) as a function of crank angle θ where θ = 0 at BDC.

APPENDIX B: MECHANICAL DESIGN PROBLEM STATEMENT

1. Make engineering drawings of all the parts you made for your compressor, including

   - Head plate
   - Motor mounting plate
   - Cylinder
   - Piston
   - Connecting Rod
   - Any additional parts you made

   Each drawing should include three views (orthographic projection) of the part and all dimensions. The drawings should be made on a computer. Make an assembly drawing, showing all parts together. An example assembly drawing is shown below.

2. Calculate and plot the following curves:
   - Crank torque vs. crank angle
   - Piston position vs. crank angle
   - Piston velocity vs. crank angle

3. Complete a 1 page write-up of the compressor project. Include a bill of materials needed to build a compressor (including fasteners.) In the write-up, describe your design and characterize its performance. How would you improve your design?