18 September, 2009

Dear NFPA Education Committee and Foundation Board:

I am writing to express my gratitude for the funding you have provided to support introduction of pneumatics into the MIT subject 2.007 – Design and Manyfacturing I. This funding was absolutely essential to evolving the course to enable more creative options and to link it more strongly with the core Mechanical Engineering subjects of fluids and thermodynamics. I personally observed many students succeed in developing robots to apply large forces and to rapidly grasp and manipulate objects. This was greatly facilitated by the pneumatic components provided in their robotic kits.

Taking on the lead role in a course like 2.007 has been a major commitment for me. I am dedicated to making the course a little bit better each year. I want you to know how much I appreciate these funds that made it possible to try new things and to keep the course fresh.

Sincerely,

Daniel D. Frey
Associate Professor of Mechanical Engineering and Engineering Systems

Introduction of Pneumatics into 2.007 – Design and Manufacturing I
A Report on Curriculum Development Supported by NFPA

Dan Frey

Abstract

This document describes work related to the course “2.007 – Design and Manufacturing”. Efforts were taken in spring 2009 (and in the months leading up to that academic term) to move the course in new directions. We were motivated for many reasons including the potential changes in the General Institute Requirements to consider broadening the coverage in the course. We expanded our set of topics in design to include a greater variety of phenomena, especially pneumatics but also the electronics needed to control them. We believe the changes in the course were strongly positive. The new materials in the robot kit enabled a more diverse set of machines. Also, in many respects, we observed a more capable set of machines. For example many of the robots applied larger forces than past years and many performed tasks autonomously. Even with all the new topics to learn, the complexity of the logistics, and record enrollment (more than 180 stduents), the subject evaluations improved compared to last year.

Background

2.007 is a core Mechanical Engineering subjects that supports the Department’s educational objectives, especially those related to design and manufacturing. As the catalog description explains, 2.007 places “emphasis on the creative design process bolstered by application of physical laws, and learning to complete projects on schedule and within budget.” The lecture topics have in the past emphasized mechanical design elements (gears, bearings, mechanisms, etc.) along with topics related to the design process (creativity, concept selection, and visual thinking). The course has been successful for decades in its role as a Sophomore-level introduction to mechanical design. Even though 2.007 is already an important part of the MIT culture, we still felt there were several opportunities to better serve the students. Based on our analysis of past course evaluations, we chose to broaden the content of the course, especially by ading pneumatic elements to the contest kit. We also made complementary adjustments to the assessment of student skills and the CAD instruction.

Broadening Content through Addition of Pneumatics

To make 2.007 appealing to freshen across the Institute, the design topics in 2.007 were expanded. We chose to include pneumatic elements in the contest kit. These additions pushed us to broaden the emphasis which had been most strongly on mechanical elements such as gears, bearings, and mechanisms. In 2009, we had a balance of these same mechanical elements with fluids, thermodynamics, and the electronics needed to control the system. This required some reduction in the coverage of machine elements. For example, cams were not discussed in much detail. But we feel the new balance is more reflective of modern mechanical engineering practice.

In order to get so much new material into 2.007, we decided to re-think the connection to the IAP subject 2.670 – Mechanical Engineering Tools. The vast majority of the students who pre-registered for 2.007 also pre-registered for 2.670. So, even though we did not enforce a prerequisite structure between 2.670 and 2.007, it was in fact the case that we had a chance to seed the student body with knowledge relevant to using the new components. Therefore, instead of the Stirling engine students used to build, we helped the students to build a compressed air powered robot (see Figure 1). This robot used the compressed air stored in a two liter soda bottle to propell itself forward across the ground by actuating pisons. The gait of the robot was controlled by computer programmable firing sequence of the pistons.

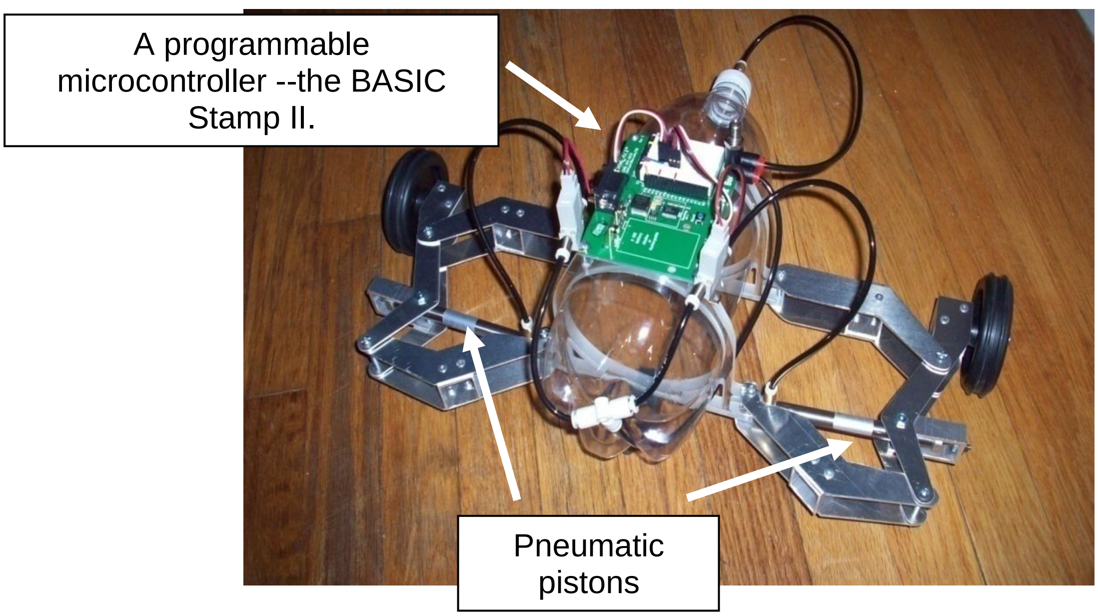

Figure 1. The compressed air powered robot built in 2.670 in IAP of 2009.

The effort to include these new elements seemed to pay off very well in the variety and performance level of the student machines. For example, Julie Henion incorporated pneumatics in her machine that could crush aluminum soda cans -- a task requiring in excess of 100 pounds of force (see Figure 2). Blake Sessions constructed a similar crushing device and also integrated it with an ultrsonic sensor to autonomously traverse the contest field and deliver the can into the scoring slot. His video is described in Figure 3 and available on-line at http://techtv.mit.edu/collections/2007videos/videos/2708-2007---blake

Figure 2. An example of student use of pneumatics – Julie Henion's can crusher.

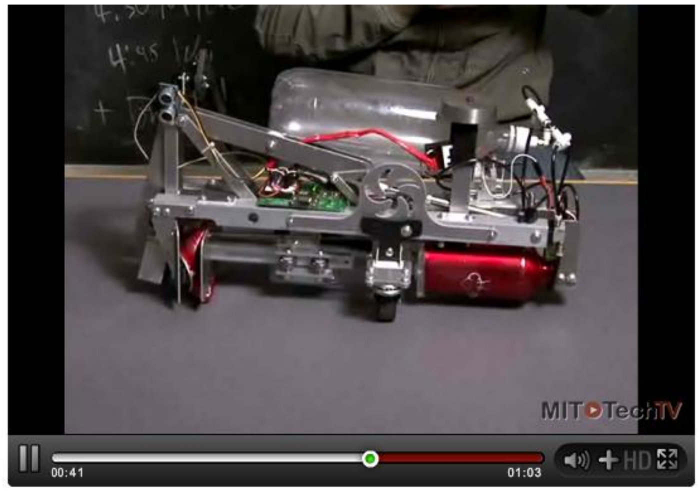

Figure 3. An example of student use of pneumatics integrated with electronics -- Blake Sessions' machine demonstration video.

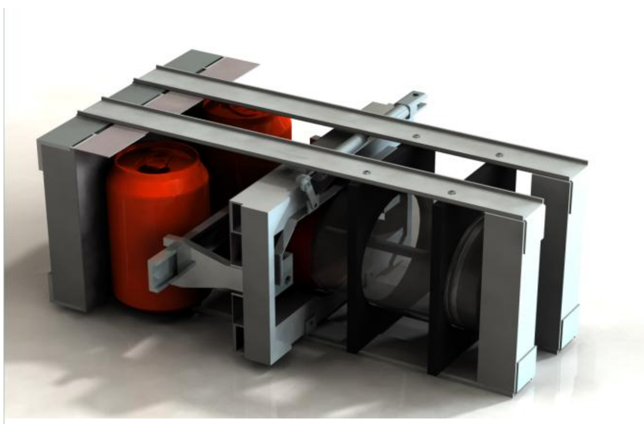

Figure 4. An example of a student's solid model – Julie Henion's can crusher.

Use of Computers in Design

In addition to the new pneumatics content, CAD was taught more explicitly within 2.007 including both its use as a design tool and some of its underlying concepts (e.g., how geometry is represeted and manipulated within the computer). New in 2009 were five lectures in Computer Aided Design developed and delivered by Prof. Dave Gossard. Following up on this, we also used CAD tools more explicitly in mechanism analysis and synthesis lectures and homeworks. As evidence of the success of this effort, we saw outstanding integrated solid models of student machines. For example, Figure 4 shows a solid model of Julie Henion's machine.

Assessment

With the addition of the new material on pneumatics, we wanted to make complementary changes in assessment of student performance. This year, half of each student's grade in 2.007 was determined by lab activities. The majority of the lab grade is the design notebook. In 2007 and 2008, the student performance on the exam was not so good, so we decided to add four homeworks to give student practice solving the kinds of problems one might justifiably expect students to be able to do on an exam. We included homework and exam items on pneumatics. The average grades on the exams were very good. On topics related to pneumatics, students demonstrated solid understanding. For an example of a homework question and an example of student work see Figure 5.

3) (25 total) You fill a two liter container with air at 60 psi gauge pressure and plan to use it as a source of power for a machine.

A) (10 points) How much energy will be required to fill the tank to 60 psi assuming that you pump the air slowly enough for the reservoir to be at thermal equilibrium (therefore P*V is constant) with the ambient air at a temperature of 20 degrees Centigrade and 1 atmosphere of pressure?

B) (5 points) What will be the temperature of the air in the tank if we fill the tank assuming that you pump the air quickly enough so that heat transfer to the surrounding air can be neglected (therefore $P{*}V^{1.4}$ is constant)?

C) (5 points) Estimate the force applied if 60 psi air at 20 degrees C is released into a piston with a 1 inch internal diameter and a two inch throw?

D) (5 points) How much energy will be released by the air if it is expanded very rapidly to ambient pressure (1 atmosphere) so that heat transfer to the surrounding air can be neglected (therefore $P{*}V^{1.4}$ is constant)?

Integral of gauge pressure has two parts: work done total and work done by atmosphere. The net is the work we need to do to compress the gas.

$$W = \int_{V_1}^{V_2} \left[P(V) - P_{atm}\right] \cdot dV$$

$$W = P_1 V_1 \int_{V_1}^{V_2} \frac{1}{V} \cdot dV - \int_{V_1}^{V_2} P_{atm} \cdot dV$$

$$W = P_1 V_1 \left[\ln(V)\right]_{V_1}^{V_2} - P_{atm} \left[V\right]_{V_1}^{V_2}$$

$$W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right) - P_{atm}(V_2 - V_1)$$

$$W = -1678J + 828J = -850J$$

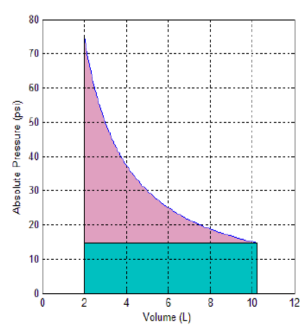

Figure 5. An examples of a homework item in 2.007 in Spring 2009 and part of a student's solution.

Evaluation of Results

The course 2.007 continues its tradition of exposing students to the process of engineering design giving them a personal experience designing an electro-mechanical device. In spring 2009, we made many substantial changes intended to make the treatment of design broader, more diverse, and more modern. At the same time, we had record enrollments with more than 180 students completing the subject this year. The quality of the delivery was improved with the Pi Tau Sigma evaluations rising about a quarter of a point on a seven point scale. Based on the faculty and department leadership's perception of the course, I was given the Rurh and Joel Spira Award for Distniguished Teaching. I also was regognized through an informal student "voting" process by the "The Institute Screw". This is a high honor indeed which may either indicate that I inadvertently made a stressful situation for the students or else that they felt comfortable enough with me to make a joke about their experience. There is still plenty of room for improvement, but I think this has been a very good start, especially given it was my first year leading a logistically complex subject.

Plans for the Future

At this stage, we are in a good position. We will continue to make small adjustments. The changes we'll implement should all be heading in the same direction we are already progressing. We'll continue to have microprocessors and CAD in the subject, but we'll probably switch from BASIC Stamp to Arduino boards so that we can more easily make analog inputs into the robots and so that students get exposure to a more modern programming language. In pneumatics, we plan to provide more formal instruction not only in the lectures, but also more explicitly support some exercises in the lab sessions.