Improving A Fluid and Thermal Sciences Course for Electrical Engineering Technology Students

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Abstract:

At Penn State Erie, Electrical Engineering Technology (EET) seniors are required to take a course in fluid and thermal sciences. The course consists of two hours of lecture and two hours of lab per week. This course has traditionally been taught by a Mechanical Engineering Technology (MET) faculty member who would teach it from a mechanical standpoint, with electronic examples brought in where possible. The labs were designed around existing equipment in the mechanical fluid and thermal sciences lab and held little significance for EET students.

Over the last several years this course has become focused on the thermal management of electronic systems. Fluid and thermal sciences topics are introduced as needed to enhance the understanding of thermal management issues. New equipment has been added to the lab which more closely matches the material being covered during the lectures. Flotherm software has been acquired to provide the opportunity for students to learn some of the thermal modeling capabilities that exist in industry. The lectures and lab experiences have been redesigned to compliment each other. This paper provides a comparison of the old course structure with the new.

I. Introduction:

At Penn State Erie the Electrical Engineering Technology (EET) students are required to take a course in fluid and thermal sciences. The published description of this course says that it is an introduction to principles of thermodynamics, heat transfer, and fluid power with applications in the areas of electrical and electronic systems. This description gives the instructor a great deal of flexibility in determining the course content.

The course has both lecture and lab content. There are two hours of lecture and two hours of lab each week. It is taught by Mechanical Engineering Technology (MET) faculty. Traditionally the areas covered in the course have been typical mechanical topics. Most of the labs were the same ones performed by the MET students. There was a recognized need to improve the course to make it more relevant to the needs and interests of the EET students. This paper provides a comparison of the old course structure with the new, a description of the steps that were taken toward this improvement, an outline of the new labs that have been developed, and future plans for continued improvements.

II. Course Improvement Objectives:

Several objectives were set for the improvement of the course:

- The course must be relevant to the needs and interests of the EET students.
- The basic concepts of thermodynamics, heat transfer, and fluid mechanics must be presented, but only as required to understand the principles of thermal management.
- The lectures and labs must relate to each other in order to enhance the learning experience.

III. Course History:

Table 1 shows the traditional course outline. The outline shows that the course was broken into three distinct sections – thermodynamics, heat transfer, and fluid power. Each section was intended to take approximately one third of the semester, and an exam was given at the end of each. Actually, the fluid power section consumed about on half of the time with the other half being divided between thermodynamics and heat transfer.

<u>Traditional Course Outline</u>

<u>Thermodynamics</u>:
- Closed and open thermodynamic systems
- First law of thermodynamics
- Pressure
- Properties of pure substances
- Steam tables
- Ideal gas laws
- Heat engines

<u>Heat Transfer</u>:
- Conduction
- Convection
- Radiation
- Combined modes
- Thermal networks
- Electrical analogy
- Fins, heat sinks

<u>Fluid Mechanics / Power</u>:
- Fluid statics
- Continuity equation
- Losses in pipes and fittings
- Principles of hydraulics
- Hydraulic schematics
- Construction of hydraulic devices

Table 1

This structure had many inherent problems. The most notable problem was that much of the material had little or no application in the electronics field. Many of the thermodynamics and heat transfer topics were relevant, but they only constituted less than half the course. Virtually none of the fluid power topics had any electronic systems applications.

The labs associated with this course were the same ones used by the MET students in their heat transfer and hydraulics courses. One of the reasons for using the same labs is that equipment for labs in these areas can be very expensive, so it was decided to use existing equipment. Two of the labs were run on a water metering flow bench. One involved calibrating a rotometer while the other involved comparing flow rate results from the rotometer, a venturi meter, and an orifice meter. The next lab was a thermodynamic analysis of a water to water heat exchanger. Measured results were compared to calculated results. For the heat transfer portion of the course, a small table top sterilizer was used for heat loss calculations and measurements. One of the labs involved programming a PLC to control a small pneumatic circuit. Finally, a hydraulics trainer was used for setting up and demonstrating a variety of hydraulic circuits.

IV. Strategy for Improvement:

The improvements to the course took about three years to complete, and continued improvement is planned beyond the three years. The plan called for changes each year leading toward a fully integrated course focusing on the thermal management of electronic systems. The main steps involved were:

- Obtain new equipment for more relevant labs
- Modify lectures to address thermal management issues
- Design and introduce new lab tests related to thermal management issues
- Polish the overall course to pull the lectures and labs into one integrated learning experience.

V. Obtain New Equipment:

As stated earlier, new equipment in this field can be expensive, so innovative methods needed to be used to obtain the necessary equipment. Student senior projects were used extensively to build some of the equipment, and the school obtained both an infrared camera and Flotherm software for use in the labs.

The first piece of equipment to be added was a low speed wind tunnel (Figure 1), built as a senior project. At the same time the wind tunnel was being built another student senior project team was building an air flow bench (Figure 2). These two pieces of equipment were constructed at low cost and are extremely useful for a variety of lab tests (see section VII). Other student teams have designed and built both a P4 thermal simulator (Figure 3) and a thermal interface material tester (Figure 4).

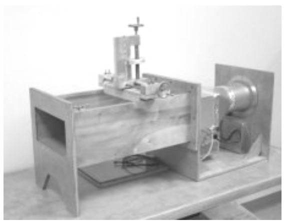

Figure 1

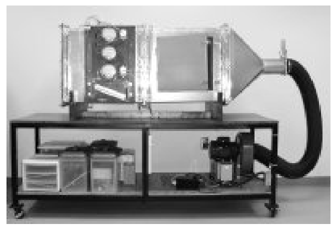

Figure 2

Figure 3

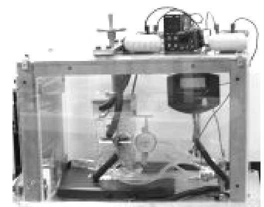

Figure 4

These four new pieces of equipment along with the infrared camera and the Flotherm software have made it possible to eliminate all of the original labs and replace them entirely with thermal management related labs.

VI. New Lecture Plan:

The latest version of the course is completely restructured. The theory from the three main areas – thermodynamics, heat transfer, and fluid mechanics is introduced only as it is needed. Applications in the area of thermal management of electronic systems are stressed throughout the course. Table 2 shows the new course outline. Notice that the course is no longer broken into distinct sections.

Many physical examples of cooling devices are brought into the classroom for the students to see, and discussions about the devices are encouraged

<u>Improved Course Outline</u>

- Introduction to thermal management issues
- First law of thermodynamics
- System level thermal issues
- Fluid statics
- Continuity equation
- Losses in pipes and fittings
- Air flow management - fans, system flow impedance
- Conduction
- Convection
- Radiation
- Combined modes
- Thermal networks – electrical analogy
- Package level thermal models
- Contact resistance, thermal interface materials
- Fins, heat sinks
- Board level thermal issues
- Introduction to thermal management devices – heat pipes, thermoelectric coolers, water cooled cold plates, etc.

Table 2

(Figure 5). Much of the theory is introduced as a response to the class discussions rather than in a rigid lecture format. This helps to keep the theory relevant to the students interests and curiosities. Most of the students have seen various devices in their home computers, on the internet, or in some of the test equipment they use in their other electronics labs. They bring up questions about these devices, and this discussion can also be used to spark a particular lecture. The order of topics is somewhat flexible to respond to particular questions brought up by the students.

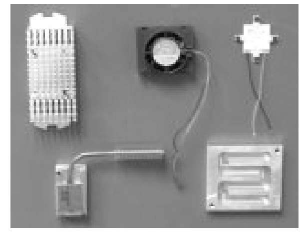

Figure 5

Homework for the course includes traditional problems to solve, but also several internet and library research projects related to the cooling devices they are seeing in class. All of the problems are related to the electronics field. An example of an introductory conduction problem would be normal to plane and in-plane conduction through a circuit board instead of the more mechanical problem of conduction through a wall.

VII. New Lab Tests:

The lab portion of the course was almost completely irrelevant to the rest of the course and has been completely changed. All of the old labs have been replaced. The new equipment described above is now used extensively for lab tests. Approximately 35-40% of the lab time is spent in the computer lab learning how to use the Flotherm software, creating models, and running simulations. The EET students are very accustomed to using simulation software in their other courses, so the use of Flotherm makes the theory from the lectures much easier for the students to absorb. Here is a brief outline of some of the labs that are now used for this course:

- First law of thermodynamics – energy balance of a hair dryer
    - This lab requires the students to measure all of the necessary data to determine the total energy coming into and exiting the hair dryer. Final results comparing incoming with outgoing energy terms usually are within 5-10%. Students are expected to discuss possible sources for error. This lab is an excellent inexpensive lab to demonstrate the first law, and helps the students to understand the concept of systems and system boundaries.

- Continuity equation – velocity profiles at two cross-sections of the low speed wind tunnel and a comparison of the total flow rate at those sections
    - In this lab students take velocity readings across a grid at two different cross sections. This data is transferred to Matlab to plot three-dimensional velocity profiles. The data is also used to calculate the total mass flow at each cross section. The method used for calculating the total mass flow is the same method used in the hair dryer lab. The total mass flow rates are compared to see if they match as the continuity equations says they must. Results within 5-10% are common, and the students are expected to discuss possible sources for error.
- Fan curves, system flow impedance curves, and determination of the operating point for a desktop computer power supply using the air flow bench
    - This is a two week lab. The first week the students learn how to operate the flow bench and how to use it to create fan curves and system flow impedance curves. They plot curves for a fan and for several perforated plates. Results are compared to published data. The second week the students create a fan curve and an impedance curve for a power supply. They superimpose the curves to predict an operating point. Then they measure the actual operating point. Results for both weeks are typically extremely close to predicted values.
- Comparison of effectiveness of commercial heat sinks for a P4 processor using the P4 simulator
    - Students are given several commercial heat sinks to test. The criteria for comparison is the maximum temperature reached on the heat source for a given power input. The students are asked to research the heat sinks and report on how their findings compare to other published comparison data. They discuss the features of each heat sink and what factors seem to improve the performance. One of the heat sinks utilizes heat pipes leading to a discussion of the operation of heat pipes.
- Measurement of the thermal conductivity of thermal interface materials
    - Thermal conductivity measurements are taken for a variety of interface materials and compared to published values. Several materials will be tested, including at least one phase change material. The report will contain a discussion of why the materials are used, comparisons of measured vs. published data, comparisons of measured conductivity vs. calculated contact resistance without the materials,

and a discussion of why phase change materials are used in these applications. This is a new addition, and results are not known at this point.

- Computer simulation assignments using Flotherm software
  - Several lab classes will be used to teach the students how to make simple models with Flotherm, and two or three basic models will be assigned. This is a new addition so this portion is not fully developed yet. Modeling and simulation will be a key focus for future course improvements.
- Comparison of Flotherm results for a variety of heat sinks with test results
  - Several heat sinks will be modeled and then tested. Results will be compared. This is a new addition, and results are not known at this point, however Mechanical Engineering students have used a similar lab with good results

Thermal management of electronic equipment is a rapidly changing field. New labs will be added to keep up with the changes in technology. Future lab additions will include a water cooled heat sink, increased use of the wind tunnel and flow bench, particularly in the area of heat sink tests, use of the infrared camera to show temperature distributions and provide comparisons with Flotherm simulations, and possible immersion and spray cooling tests.

XIII. Finishing Touches:

After the changes described above were implemented there was still room for improvement in the area of integrating the labs and lectures into a coordinated course. Originally the labs and the lectures were almost independent of each other. The class is now structured so that the lectures and the labs are designed to complement each other. This is done in two ways. Several of the labs, such as the hair dryer lab, are performed right after the theory is covered in a lecture. This method reinforces the theory for the students and gives it relevance. Other labs, such as the heat sink comparison on the P4 thermal simulator, are conducted prior to any of the theory. This seems to be a highly effective method of increasing interest in the theory. This method of introducing the material gives the students an opportunity to discover things, build a curiosity about what is happening, and break down possible preconceived ideas about how things work. Follow-up lectures teach the theory and give meaning to the discoveries. This coordination effort takes a lot of time and patience, but pays off for the students.

IX. Conclusion:

Thermal management of electronic equipment is becoming an increasingly important topic as power levels rise and size of components decreases. This type of course gives the EET student an opportunity to learn a little about the theory involved and to have the theory reinforced by a closely related lab experience. The addition of the infrared camera and the Flotherm software will greatly improve the students' ability to visualize what is going on thermally in an electronic system. Much improvement has been made, and more is planned. Future improvements will include extensive use of the infrared camera in the lab, upgrades to labs to include emerging technology, increased use of Flotherm simulations, and development of more of the discovery type labs.

Overall, this course has been popular among the students, and the continuous improvement should only enhance that popularity. Typical student evaluations have increased steadily as the changes have been implemented. The key to the success of the course is making it relevant to the students' interests and keeping it current in a rapidly changing environment.

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Robert Edwards is currently a Lecturer in Engineering at The Pennsylvania State University at Erie where he teaches Statics, Dynamics, Economics, and Fluid and Thermal Science courses. He earned a BS degree in Mechanical Engineering from Rochester Institute of Technology and an MS degree in Mechanical Engineering from Gannon University.