Development of a Teaching Tool: the Texaco Energy Systems Laboratory at Penn State

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Abstract *- The importance of developing improved teaching tools for design of thermal systems has been recognized at Penn State. This paper describes an undergraduate energy systems laboratory to be implemented at the Mechanical Engineering Department, under primary sponsorship from Texaco, NSF and internal matching funds. This lab will be implemented by judicious selection of test stands allowing the students to experiment with actual machines. Three test stands have been procured in order to allow the students to exercise and reinforce the theoretical knowledge acquired in the thermal courses, and to appreciate the comprehensive nature of design activities. We plan to have an IC engine, a steam Rankine cycle and a refrigeration system. Other issues illustrating the integrating nature of the design activity, such as considerations of vibration, noise, fatigue, material selection and environmental compliance will also be addressed as the Lab develops.*

Introduction

Among other skills, our species has developed that of harnessing increasing quantities of energy. Much has happened since our ancestors started to use fire to advantage. We show in Fig 1., largely based on data from [1], the evolutionary progress in production and control of power. One of the chiefs provinces of mechanical engineers is the design and operation of the energy systems of increasing capacity and energy density.

It is clear that an energy systems laboratory is of crucial importance to undergraduate students. Texaco and the faculty at PSU recognized the need to develop the students in this important area of endeavor. The guiding principle was to improve education on thermal systems by providing "hands on" experience on thermal systems. The experience content is that of design integration, across disciplines and system boundaries [2]. This paper reports on the progress achieved to date in developing this lab.

Goals

Repeated surveys of our undergraduate population have indicated that "hands-on" experiences are very much demanded as part of engineering education. To supply these type of experiences is a difficult proposition, because of cost, space and the existence of a fully established curriculum. Truly valuable experiences allow abstraction of information that can be applied in different situations. Hence, out guiding goal was to provide a site to experiment with basic aspects of thermal system design.

In the realm of thermal systems, enhancing the understanding of the First Law and the Second Law is fundamental to good designs. Whereas the first Law is easily grasped, the Second, and many of its ramifications, are not always shared by all students. For many, entropy is a property of uncertain definition and of obscure meaning. Yet, entropy leads to exergy, one of the most useful tools for thermal system characterization. Co-generation, energy cascading, heat recovery and advanced systems can be readily justified and improved using Second Law concepts.

In addition, the Second Law indicates that cyclic energy transformations will require heat rejection. In practice, heat rejection is accompanied by rejection of substances (oxides of carbon and of nitrogen, radioactive products and waste, heavy metals, particulates) not always deemed desirable by some (or all) sectors of Society. Even renewable cycles relying on complex atmospheric phenomena for heat rejection (wind, hydro) are questioned by some on the basis of the surface area that they demand. The consequences of the Second law regarding pollution, global warming and other important issues are hard to ignore, for they are increasingly regulated. Hence, one of our aims is to illustrate thermal system integration and how the Second Law can provide a yardstick for design evaluation.

Our interactions with practitioners over the years yielded two other matters of importance for education in

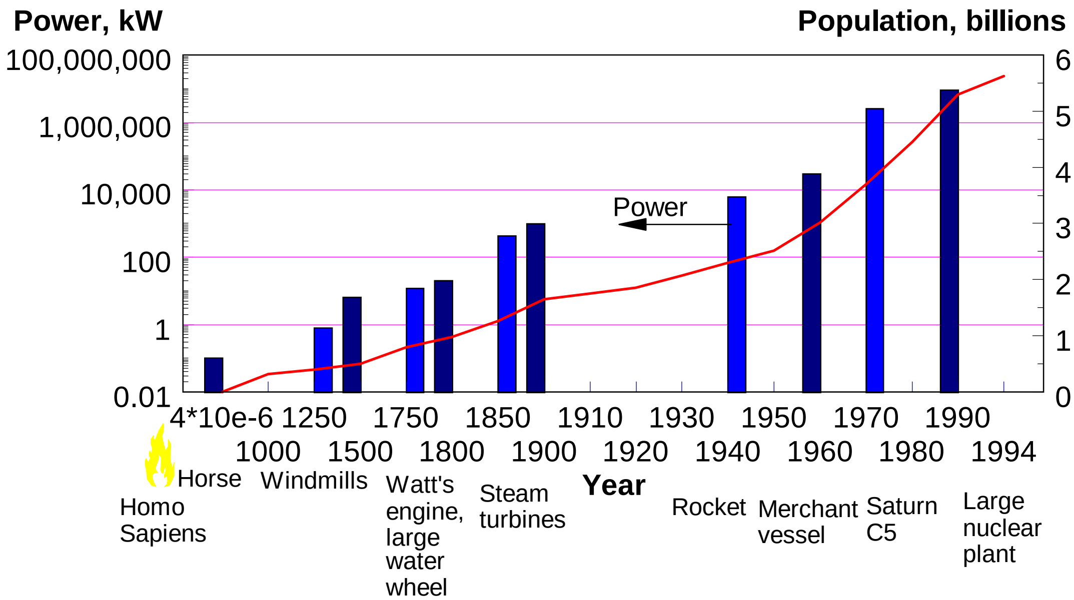

Fig 1. Increasing population and capability to harness energy vs. time.

thermal systems: reliability, and compactness. Reliability measurements vary from power plants to refrigerators, but the idea behind reliability is that of design integration. Design of thermal systems is a broad area. Top designers in each technology usually exhibit integrative knowledge of thermodynamics, heat and mass transfer, materials application and compatibility, machine design and aesthetics. To illustrate via experiments the integrative nature of the design activity is another goal of this laboratory.

Finally, compactness, as illustrated for instance by the weight to power ratio of airplane powerplants, ranging from 8 g/watt early in the century to 0.02 g/watt nowadays [1], is a permanent design trend. Progress in size reduction comes about as new materials, heat transfer techniques and improved lubrication allow the release, transfer and conversion of energy in smaller volumes and through smaller surfaces than before. It is one of our goals to illustrate this trend of size reduction via judiciously chosen figures and charts displayed in the lab.

The Laboratory

The integrating nature of design can be best illustrated by practical examples embodied in experimental stands. An IC engine, a steam engine and a refrigeration unit test stands have been procured . The location of the components relative to electrical and water supplies and drains is shown in Fig 2. Both engines can be connected to a dynamometer to measure speed and torque. In addition to the test stands of Table 1, an air to chilled water heat exchanger was designed and built by students to fulfill the dual purpose of removing waste heat from the room (1.5 kW), and of measuring overall heat transfer coefficients of the air-to-water finned coil. Below, we include a brief description of each component and the rationale for selection.

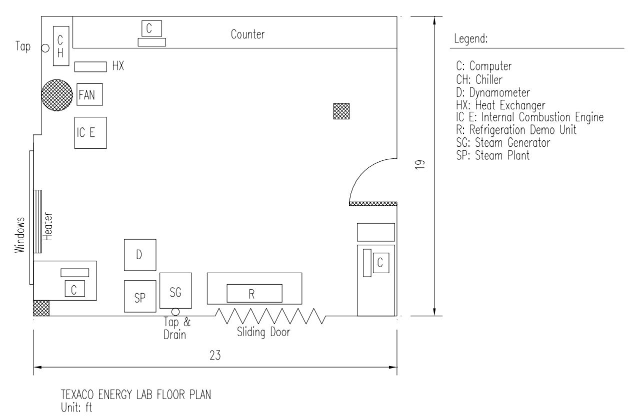

Fig 2. Laboratory layout, with components.

IC Engine

The unit is a single cylinder, air-cooled four-stroke gasoline IC engine, provided by an educational supplier. The engine output is 1.5 kW at 3600 rpm. The engine is packaged in a test stand with provisions to measure air inlet flow and fuel flow. The air inlet flow is measured with an orifice plate, whereas the fuel flow is measured via a graduated cylinder and a chronometer. The engine shaft has a small flywheel and a pulley. A timing belt connects the pulley to that of a dynamometer. The dynamometer, a swinging field machine, measures engine torque. An inductive tachometer measures dynamometer rpm, and the engine rpm can be readily determined from the pulley teeth ratio. The test stand includes a four-channel thermocouple display. Currently, air inlet and outlet temperatures are measured.

The IC engine was chosen due to its importance as a prime mover for transportation. Clearly, the sponsor has a strong interest in disseminating information about this type of engine. The test stand illustrates aspects of conversion of chemical to mechanical energy, lubrication and instrumentation for measuring power output. Also, it lends "hands-on" experience in terms of engine control and operational temperatures, which largely determine exhaust materials. The impact of fuel-to-air ratio on performance can also be readily assessed, illustrating the importance of properly adjusted injection systems.

Software developed specifically for this test stand guides the students through a typical test. The program was developed in the LabWindows® environment, based on the C language. When a test is started, the computer displays an image of the Dynamometer control panel, Fig 3. The program guides the student through the data taking process, allowing manual entry of data in each field. Upon completion of a run, the program calculates a number of parameters such as power output, thermal efficiency and fuel consumption among others. It is possible to readily generate performance curves with speed as the independent parameter for the engine.

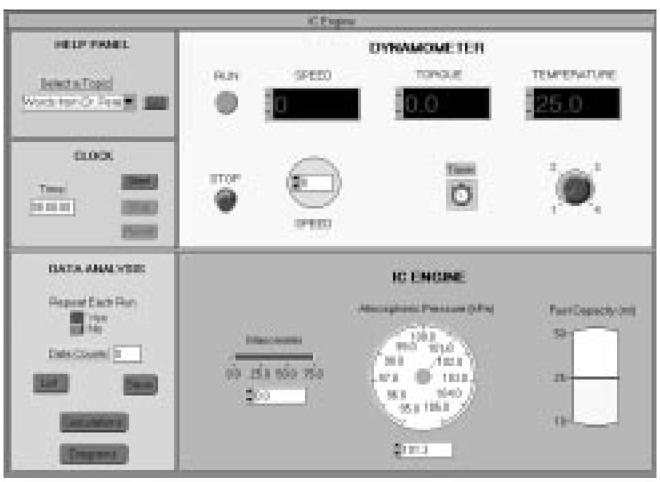

Fig 3. IC Engine software interface.

Both authors' professional experience included automated data acquisition as well as manual. Whereas automated data acquisition is useful for productivity and accuracy in many test stands, its use in our particular application may not be warranted. When students are attempting to develop a feeling for "typical" operating values, it appeared that the act of reading an instrument and entering the data in a visually attractive interface would provide a more fruitful experience than automated data acquisition. The simplicity of our experiments, and the intent of furnishing a more complete learning experience, led us to adopt the manual entering approach.

Refrigerator Test Stand

Refrigeration is of paramount importance for food processing and preservation, and air conditioning is a growing energy consumer. Hence, an illustration of refrigeration cycles was deemed of sufficient importance to this lab. Cooling cycles can be activated by mechanical or thermal energy. In our economy, mechanical is the prevalent way of activation, and hence a vapor compression cycle was incorporated in the lab.

The test stand, also procured from a commercial supplier, offers an excellent opportunity to appraise the integrative nature of design. Refrigerant handling must comply with environmental constraints, and the compressor must have enough oil for reliable operation. The oil must be compatible with the refrigerant. The importance of heat transfer in design is amply illustrated here. The glass shell of the evaporator and condenser, coupled with lighting, allows ready observation of boiling and condensation processes.

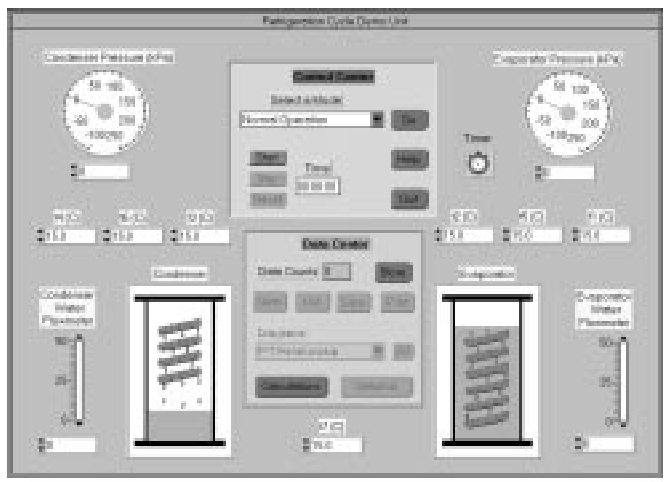

Fig 4. Refrigerator test stand software interface.

The rated compressor power consumption is 810 watts, and the students can measure coolant and chilled water flow, along with refrigerant temperatures at various points of the cycle. High and low pressures can also be recorded. Similar to the IC engine, a computer program guides the data acquisition and processing. A display of the system (Fig 4) serves as an interface between the student and the program. Test data can be input or dialed, and several processing options are available. These options range from studying the pressure vs. temperature curve, to calculating refrigerator capacity.

Steam Engine

Power generation is done via Rankine cycles in most base plants. Hence, it is important to illustrate the conversion of thermal energy into mechanical energy using steam. A small, two cylinder self starting single acting engine, developing 520 W at 30 kg/hr with saturated steam at 100 psig and condenser inlet water temperature of 25 C with 90 kg/hr coolant flow. Steam is provided by an electrical boiler. The engine can be connected to a dynamometer similar to the one described under the IC engine heading. In this way, torque and speed can be monitored. The condenser load can be determined from flow and temperature measurements, and the inlet steam enthalpy can be ascertained via a calorimeter. Software for this test stand is still under development.

Chiller Unit

Early in the project it was determined that the boiler and the IC engine will dissipate heat into the room, and that the existing A/C system may not be sufficient to remove all of the heat. Consequently, a project to provide a chiller with 1.5 kW capacity was started under the direction of one of the authors in a thermal design course. The outcome of this project is a system comprised of an air-to-water coil and a water chiller. Air blown over the coil is cooled by water from the chiller. The students designed and implemented the air-handling unit and instrumentation to determine the overall heat transfer coefficient of the coil.

The Second Law

To promote the thinking that goes along with thermal system integration, the students will be asked to calculate not only figures of merit based on the First Law, but also figures of merit based on the Second Law. For instance, an exergetic analysis of the internal combustion engine could be useful towards illustrating the flows of exergy. The exercise of creativity is perhaps one of the stronger assets that a teaching laboratory can offer [4]. However, it is not easy to modify the thermal systems currently planned, which have been selected on cost and compatibility reasons. Advanced software for thermal system design is under consideration, to allow students the latitude of exploring and creating thermal systems, combination of simple ones, that are original and serve a need. The search and development of suitable programs is now underway.

Conclusion

In a recent article, the thesis was advanced that teaching must be enduring, effective and entertaining [5]. We certainly agree, largely based on our own experience. The difficulties in topics that arise our interests are really challenges, rather than difficulties. Overcoming the challenges seems then like a worthwhile way to spend our time. This opinion, coupled with the observation that students are interested in “real problems”, led us to implement a laboratory with a definitive slant towards realism.

Like most educational undertakings, the Texaco Energy Lab is an evolving development. Our guiding principle is to increase the capabilities of our engineers to serve the interests of Society with enlightened thermal designs. The scope of a modern energy lab is breathtaking: from materials compatibility to system integration, the skills required for design are certainly interdisciplinary. The breadth and depth of knowledge that the Lab may show to be necessary could help students set goals for their careers.

Whereas the test stands should be operational in the short term, selection of modeling software offers serious technical and conceptual challenges. The path to truly enlightening interactive design programs is still unclear. As of this writing, the modeling software component of the Laboratory is still in the planning stages.

Acknowledgments

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