

Learning About Engineering Design Through Product Dissection

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Abstract

The electromechanical watt-hour meter is a familiar sight on utility posts and buildings everywhere. Millions of these meters register electrical energy use for the purpose of revenue billing by electric power suppliers. Watt-hour meters are excellent engineered products for learning about the engineering design process and the engineering disciplines through the use of reverse engineering or product dissection. At Iowa State University, we are using these meters to provide an experiential, hands-on mechatronics laboratory for junior high, high school, and freshmen engineering students. This paper describes the process used in the mechatronic laboratory and many opportunities for using these engineering masterpieces.

I. Introduction

Electromechanical watt-hour meters have been under continuous development since 1888, when Oliver Shallenberger and Thomas Duncan built a working model¹. As a result of this development, modern meters, such as the three-wire single-phase model shown in Figure 1, are masterpieces of engineering design. These meters:

- Operate with a registration error of less than 0.5 % over a load range of 0.5 to 100 percent of maximum load.
- Maintain high reliability while withstanding direct sunlight, arctic cold, tampering, and blows from irate customers.
- Have a working life of up to 50 years.
- Can be purchased new for under \$30.

As watt-hour meters become defective or obsolete, they are replaced. In Iowa, with over 1.4 million meters in use, two to three percent (28,000 to 42,000 watt-hour meters) are replaced each year. Most of these meters are discarded and end up in landfills. Some power suppliers will supply discarded meters for educational use.

The electromechanical watt-hour meter is ideal for reverse engineering exercises or product dissection for the following reasons:

- Meters are readily available at little or no cost.
- Meters can be safely disassembled with simple tools.
- Components can be easily identified during disassembly, and can be utilized in learning the meter's principles of operation
- Design, development, assembly, sales, and utilization of watt-hour meters involves virtually every engineering discipline.
- A wide variety of materials can be identified among the meter parts.

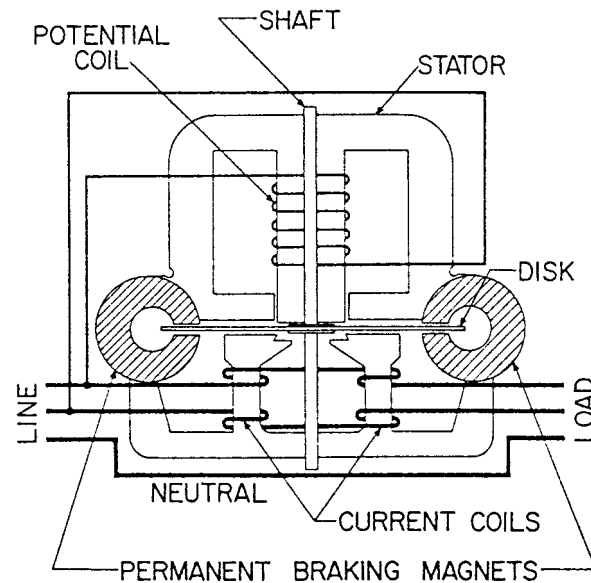


Figure 1. Three wire, single-phase electromechanical watt-hour meter schematic diagram².

II. Background

Product dissection or “mechanical dissection” has become a popular way in which to teach students at all levels of education about engineering concepts and design principles related to engineered products around them. At ISU we have been using product dissection in our introductory engineering graphics and design course for the past six years³. This development was part of the NSF Engineering Synthesis Coalition begun in 1993. The Synthesis Coalition was a union of diverse institutions supported by the National Science Foundation. The key issues and concepts addressed in the Synthesis model, as stated in the Strategic Plan of the Synthesis Coalition⁴ were:

1. Synthesis Interdisciplinary Content
2. Concurrent Engineering and Industrial Practice
3. Laboratory/Hands-On Experience
4. Communication and Social Context
5. Advanced Delivery Systems and Learning Environments

Product dissection helped to address items 2-4, with the strongest emphasis on meaningful experiential, hands-on laboratories that enhanced learning of the engineering design process. Product dissection projects at ISU and other Coalition schools have included systems such as drills, bicycles, internal combustion engines, transmission, and robots^{5,6}. The success of getting students excited about the field of engineering and the design process through product dissection and other hands-on laboratories is well documented^{6,7,8}.

III. The watt-hour meter evaluation and product dissection laboratory

The watt-hour meter can be used to teach many aspects of the engineering design process. The breadth and depth that one might want to cover depends on the time allotted to the specific class or event. For most of the events that we use the watt-hour meter, we have no more than two hours, and in many cases only one hour. The lab is typically broken into five major components:

- A. Background
- B. Functionality
- C. Product dissection
- D. Part identification
- E. Discussion

Each of these components will be discussed here in more detail.

A. Background

When starting the lab period it is important to get the students engaged in the topic at hand. Students are asked to respond to the following questions:

- How is energy consumption measured for a typical family residence?
- What is the purpose of the watt-hour meter?
- Who owns the watt-hour meter?
- What kinds of conditions does the watt-hour meter need to withstand?
- What are the energy sources used for creating electrical power?
- Which energy source accounts for 57 percent of the electricity consumed by American households and businesses?

This can be done in a large group setting or by using “simultaneous explanation pairs” as described by Johnson et al. (1991)⁹. Time is the defining factor here.

B. Functionality

To help students better understand how the watt-hour meter functions, the students are divided into pairs and given a working watt-hour meter to conduct power usage measurements. Each team is given a common household electrical device for determining its power usage in watts. Typical devices used include items such as a toaster, drill, hair dryer, clothes iron, vacuum, slide projector, overhead projector, and solder iron. The potential devices are endless.

Students are first asked to locate the Kh value on the faceplate of the watt-hour meter. Figure 2 shows the faceplate with the Kh value as 2. The Kh value is the meter constant, which is also the number of watt-hours per turn of the watt-hour meter's disk. After plugging the household device into the watt-hour meter set up for lab measurements, the team counts the number of revolutions over a specified time period (Figure 3). To determine the power used (watts) by the assigned device, the students are asked to multiply the meter constant (Kh) found on the register plate by the number of revolutions of watt-hour disk. An example calculation is shown below for a Kh value of 2 and a count of 7 revolutions in 66 seconds.



Figure 2. The faceplate of a Westinghouse watt-hour meter



Figure 3. Power use measurement of a clothes iron using a watt-hour meter

Power use = 2 watt-hours/revolution * 7 revolutions/ 66 seconds * 3600 seconds/ 1 hour

The answer would be: Power use = 764 watts

The students are then asked to calculate the yearly cost of using this device if it was used for 10 hours a week at an electrical energy cost of \$0.09/kilowatt-hour. The calculation for the previous example would be:

Cost = 763.6 watts * 1 kilowatt/1000 watts * 10 hours/week * \$0.09/kilowatt-hour * 52 weeks/year

Multiplying and canceling the appropriate units, the answer would be:

Cost = \$35.74

Teams are then asked to report their finding to the rest of the class and discuss the differences. Figure 4 shows results from a group of students attending the ISU Engineering Workshop in the summer of 1999.

This part of the lab takes about one hour to complete. This portion of the lab can be used on its own if time is an issue.

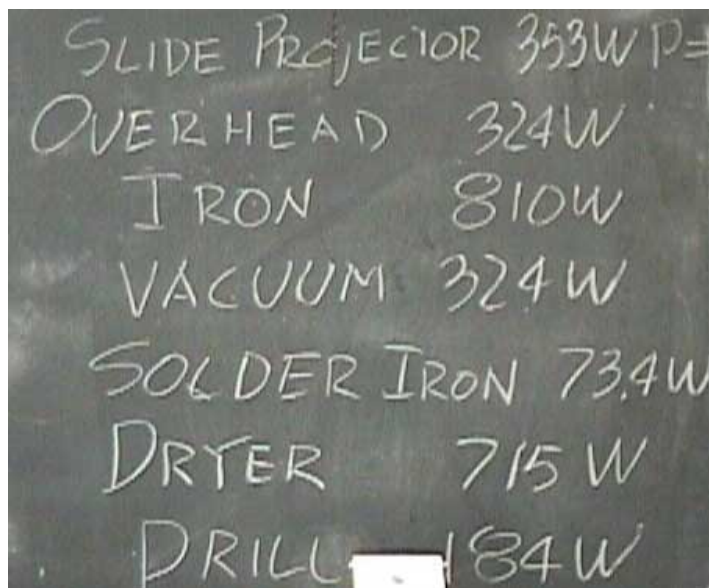


Figure 4. Power usage for several household devices using a watt-hour meter.

C. Product dissection

Before the product dissection portion of the laboratory can be completed, it is important to introduce students to the main components of the watt-hour meter. This can be done in a short lecture format as is shown in figure 5 or by using a technique called “read-and-explain pairs”¹⁰.

With read-and-explain pairs, the students are each given a short write-up on the main components of the watt-hour meter. Both members become experts on the assigned material. Students are to agree on the meaning of each paragraph, formulate one summary, and be able to explain the meaning of their answer. This is an effective way to have the students learn about the material in a cooperative manner, in comparison to a lecture format. Excellent resources that cover the main components of the watt-hour meter can be found on the world wide web¹¹.

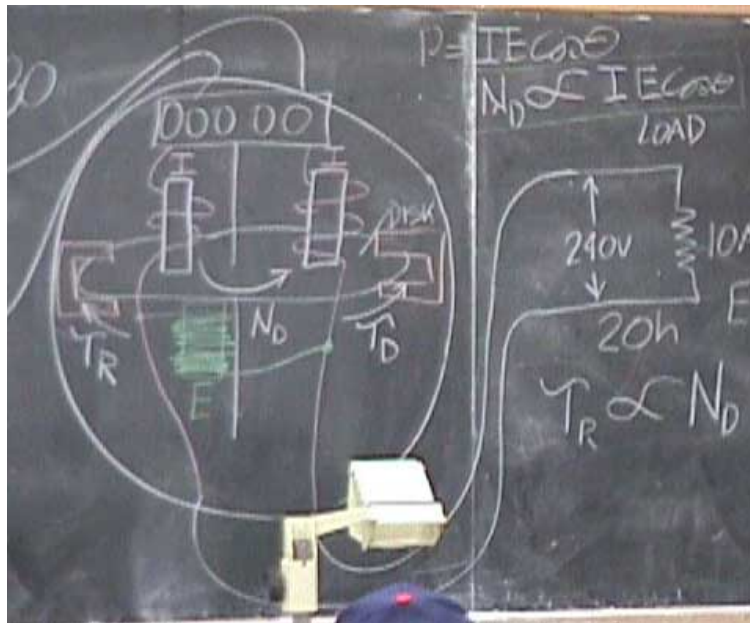


Figure 5. Lecture notes on functionality and components of a watt-hour meter

D. Part identification

After the students have learned about the major components of the watt-hour meter, the pair of students is asked to go to a workbench and dissect an assigned watt-hour meter using a set of mechanical tools. Each component must be completely removed and identified. Each team is asked to identify and explain the functionality of each component of the watt-hour meter. The major components include the:

- Register – displays the total kilowatt-hour usage
- Current coils – produce a flux field whose strength is proportional to amperes drawn by the customer's load; large wire with only a few turns
- Voltage coil – produces flux field with a strength proportional to the voltage across the customers load; made up of many turns of fine wire
- Disk – rotor, it is the movable portion; turns are proportional to the energy used
- Retarding magnets – permanent magnets arranged on top and bottom of the disk; used to produce a retarding torque on the disk proportional to the disks rotational speed.

Fortunately, most watt-hour meters are fairly easy to disassemble (Figure 6). The dissection portion of the laboratory takes about 45 minutes to complete. Student are warned about safety issue related to the tools and are warned about taking the magnet from the meter and placing them close to computer disks and hard drives.



Figure 6. Disassembled watt-hour meter, showing major components

E. Discussion

The final part of the lab is to review what the students have learned by using and dissecting the watt-hour meter. It is important to go back over the value of evaluating existing engineering designs through the process of product testing and dissection. Students can be asked several questions related to the design at this point. For example:

- What engineering disciplines might have been involved in the design and manufacturing of this device? Consider each component in turn.
- What criteria (desirable characteristics) were used in evaluating this design against other design possibilities?
- What constraints (limits) were probably placed on this design?
- What improvements could be made to the existing design?
- What safety features have been considered with this design?
- What is the importance of the material used for each part?
- If coal is the main source of fuel for creating electricity and power plants only 30 percent efficient in converting this energy source to electricity, what does this mean to the environment? Where does the other 70 percent end up?
- If 3.7 pounds of CO₂ is created for every pound of coal burned, and about one pound of coal is required to generate one kilowatt-hour of electrical energy, how many pounds of CO₂ is released each year by an individual using a hair dryer 10 minutes a day?

IV. Applications of the watt-hour meter laboratory

The watt-hour meter laboratory has been used to expose junior high, high school, and freshmen engineering students to the engineering design process and the engineering profession. Here are a few of the groups that have participated in this lab.

A. ISU Engineering Honors workshop

Each summer at ISU, the College of Engineering (COE) offers a weeklong workshop for high school students who have just finished their junior year. The purpose of the workshop is to expose these students to the engineering profession, to the ISU campus, and to as many engineering disciplines as possible. The ultimate goal is to recruit these students into our college after graduation from high school. This has been a very successful program. The workshop is offered three times during the month of July. As a part of the workshop, the students participate in a two-hour reverse engineering, product dissection laboratory using the watt-hour meter. Feedback from these students has been that the lab is a valuable experience.

B. Fundamental of Agricultural and Biosystems Engineering Course

The department of Agricultural and Biosystems Engineering has developed a one-credit experiential, hands-on laboratory course to help in the retention of their freshmen students. One lab is the reverse engineering of the watt-hour meter. This lab ranks as one of the most popular amongst these students each semester.

C. Career Trek

The ISU Extension Service offers several engineering learning experiences for junior high students across the State of Iowa. During their visits to campus, the students are given the opportunity to experience engineer laboratories that might increase their interest in pursuing an engineer degree someday. These have ranged from 3D solid modeling to the reverse engineering of the watt-hour meter. The students always seem to enjoy the hands-on experience of the watt-hour meter.

V. Example Application: Leadership through Academic Diversity (LEAD) program

Engineering 104 is a class for minority students in the LEAD Program- Leadership through Academic Diversity. LEAD is a College of Engineering program for recruiting and retaining underrepresented minority students. The course meets twice a week and is a one credit graded course. In the fall semester of 1999, the curriculum for ENGR 104 was changed to reflect a change in instructional philosophy and course goals. The published objectives for the course are as follows:

Engineering 104x is designed to assist LEAD students in making a successful transition to Iowa State University (ISU) and the College of Engineering (COE). 104x will also help make the bridge between coursework and real work. Students will learn about more about the engineering profession and the skills needed to be successful in engineering at ISU. Students will have the

opportunity to work in a team and develop skills to work effectively as a member of a team; teamwork skills are critical in engineering industry. Students will also be informed of LEAD Program, ISU, and COE opportunities and events.

As part of the course, the instructor ended the first day of class by having the students answer a question- “What is one thing I can do in this class to help you be successful here at ISU?” The responses were varied, but one of the themes developed was relating current and future course material to real work. Here are some of their responses:

“The one thing that would help me to succeed the most here would be to show me how and why the classes I’m currently taking link to Engineering.”

“Learn to be more interested in the Engineering Field (helping me relate to the Engineers in the ‘Real World’).”

“The one thing that you could do to make us more successful is give me variety in Engineering. Variety as in how what we learn in your class can relate to our everyday lives.”

“I would like to know what my classes have to do with Engineering. How does memorizing a formula or learning a Calculus technique help me to be an Engineer.”

During the following class, the instructor led a discussion about the responses to gauge student interest in class topics. When the topic of doing hands-on experiments to answer the address the above responses was mentioned, all thirty-one students in the class agreed this topic was important.

Product Dissection was already available and being used for the Engineering Honors Workshop. After meeting and discussing the exercise we discussed a modification to the exercise that included group research and class discussion. After coordinating resources, we were able to create the following components for the class exercise:

- Introduction to the watt-hour meter
- Discussion of components
- Laboratory exercise (Power Consumption Lab)
- Group paper on Energy-Star-Compliant devices and impact on power consumption
- Class discussion
- Relevance to engineering and engineering disciplines

Each lab component is discussed in more detail below:

A. Introduction to the watt-hour meter

The instructor used the class period before the Product Dissection Lab to introduce how a watt-hour meter is used and how it works.

B. Discussion of components

The students inspected the meters. The pre-lab discussion reviewed how the meters worked. Little information beyond how to take measurements with the meters was presented. Students asked questions about how power consumption was measured, and why the meters had different calibrations.

C. Laboratory exercise (Power Consumption Lab)

The idea of the lab was to generate discussion by immersing the students in the activity. Students were placed in random groups. Each group had a workstation, meter, and an electrical appliance. The group of test appliances included devices as small as a hair dryer to devices as large as an air conditioner. Discussion of components occurred during the exercise. Most groups were given electrical appliances with variable speeds. Each group calculated power consumption at multiple device speeds. The groups recorded the data, then calculated the power consumption for the appliances.

D. Group paper on Energy-Star-Compliant devices and impact on power consumption

At completion of the exercise, each group was told to submit a one-page report on Energy Star and its impact on power consumption. The group only had to submit one report for all members.

E. Class Discussion

The following class period, the class held a discussion based on their experience with the lab exercise and the reports. The students covered all the issues the instructor planned for the discussion. The students then talked about alternative power sources, and the benefits and liabilities of each. The discussion also involved brainstorming some of the engineering required to make alternative energy sources viable and efficient.

F. Relevance to Engineering and Engineering Disciplines

The discussion ended with examining the importance of power consumption to all engineering disciplines. The lab exercise was conducted in an Agricultural and Biosystems Engineering Department laboratory, yet many students thought this was a topic to be explored in an electrical engineering facility.

G. Conclusions

The students expressed satisfaction at being able to relate the exercise to something "real". What each student learned from the exercise is different. One student expressed the desire to obtain a watt-hour meter to measure power consumption on devices in his dormitory room. Another was excited to learn the use for watt-hour meters. Other students wanted more information and hands-on activities.

For future classes, the exercise can be expanded to include dissection of the meter, discussion of the materials and engineering involved in designing and manufacturing the meter, the chemistry of energy consumption (environmental issues), and the physics of the meters. Another important addition involves the experiences of a NASA Co-op Student from Iowa State. NASA hired and trained an Iowa State student to calculate power consumption demands for devices during Space Shuttle missions. Adding the experiences of this student would be powerful.

V. Summary/Conclusions

The watt-hour meter is an engineering masterpiece that has been honed for over 100 years. Due to the large numbers that are retired each year in our society, they are easily available for educational purposes. At Iowa State University we have successfully used the watt-hour meter with junior high, high school, and engineering freshmen students to provide a hands-on look at the engineering design process and profession. Students are able to evaluate the existing design using readily available household devices and then are able to use product dissection to better understand the engineering that has gone into making the watt-hour meter the efficient design that it is today. Students have been enthusiastic about this hands-on, experiential approach for learning about the engineering profession.

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