APPLIED THERMODYNAMICS – USING A SIMPLE STIRLING ENGINE TO BRIDGE THE THEORY-PRACTICE DIVIDE

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ABSTRACT

Students in the Design Analysis stream of Mechanical Engineering Technology at SAIT Polytechnic take two courses in Thermodynamics focused on the idealized analysis of engine cycles and basic heat and mass transfer. The second of the two courses is heavily theoretical and is at odds with the practical nature of the program. The author has implemented a course project using an exercise proposed by Dr. Knud Erik Meyer of the Technical University of Denmark [1] wherein students are asked to design and build a heat engine using materials cheaply and easily obtained to connect theoretical models discussed in class with a functioning device. Initially the students were charged with creating an operational Stirling engine of their own design and asked to provide an analysis of the heat engine using modeling techniques covered in class. In the second phase of the project, students were encouraged to use the analysis of the engine that they had completed to optimize the design and to improve the functional model. In the final evaluation, the students were to demonstrate revised devices and compete for the highest output power and thermal efficiency. Students reported considerable difficulty in fabricating a functioning engine, and the overall quality of the construction and level of success with the project was quite low.

KEYWORDS

Stirling Engine, Thermodynamics, Heat Transfer, Second-Year Course, Design-Implement.

INTRODUCTION

The author has undertaken the re-design and development of a fifteen-week course in Thermodynamics and Heat transfer, presented in semester three of a two-year diploma program in Mechanical Engineering Technology. Prior to beginning this class, students have completed a half credit introductory course in Thermodynamics, basic courses in engineering design, drawing, technical modeling, statics and dynamics, a shop skills class andare studying geometric dimensioning and tolerancing concurrently.

Building on the material presented in the introductory course, the second year full-credit course centers on two primary topics; the analysis of power cycles, and the primary forms of heat transfer. The material has, to date, been presented in a lecture-based format using traditional evaluations – typically two examinations worth 30% each, and a series of quizzes and written assignments for submission comprising the remaining 40%.

While this approach has provided an acceptable experience for the students, who have been able to demonstrate a basic knowledge of major concepts and proficiency with the analytical techniques presented in the class in the written evaluations, there has been a marked inability to apply these same techniques outside of the class. This becomes evident in the final semester of the program wherein the students participate in a group capstone design project. These projects vary considerably, and while not all lend themselves to using these techniques to influence design decisions, many benefit from the direct application of concepts presented in this course. Confronted with these problems however, students typically avoid using analytical methods in favour of empirical approaches. In the course of designing a steel plate to encourage uniform heat dissipation, for example, a student group employed a trial and error approach using a thermal imaging camera to select an ideal solution rather than employ basic heat transfer principles and modeling to arrive at an optimized theoretical solution before proceeding with prototyping and testing.

This apparent aversion to integrating the course material in design projects is unsettling, and has led the author to conclude that while students are able to demonstrate aptitude and understanding of the material in the context of the class, there remains a fundamental disconnect between this demonstrated understanding and an ability to apply it in a meaningful way to an open ended design problem. In an attempt to address this, a design project based on the Stirling Engine project presented by Meyer [1] was integrated into the course as a means for exposing students to a practical problem concurrent to the study of the associated theory. In doing so, it is hoped that the students may better see opportunities for applying these techniques in design practice and be less averse to using them when confronted with a design problem in the future.

PROJECT STRUCTURE AND OBJECTIVES

In order to work within the existing structure of the class while testing a design project as a critical component, a project was introduced in place of the in-class quiz mark. As such, 20% of the final grade would be assigned to the students based on their design, production, analysis and optimization of a Stirling Engine.

Students were provided with basic instructions for the construction of a beta type engine, similar to those provided by Meyer for the in-class construction of the Stirling engine [1]. They were however invited and encouraged to research alternate types and designs of engines available through tutorials online and were in no way limited to the type of engine (alpha, beta or gamma), scale or materials used.

Additional criteria dictated that the low temperature heat sink be the ambient classroom air, and the high temperature heat source be a single tea-light style candle. Total material costs were $5 (CAD) to encourage the use of recycled material and prevent students from ordering kits or pre-built components.

Initially, two design reviews were planned with an associated grade of 10% each. At the first review, the students were expected to have produced at functioning engine and were evaluated based only on engine function, general construction and adherence to the established criteria. At the second review, students were expected to improve their engines based on the principles of heat transfer that had since been presented in class, and were asked to compete for overall efficiency and shaft power output. They were, at this point, also required to submit a brief design report providing an analysis of the engine anticipating the power output and outlining revisions made to the original design.

PRELIMINARY RESULTS

At the interim design review, in which students were expected to have constructed a working Stirling engine, results were abysmal. Only two groups of the twenty-two working teams across two sections of the class had been able to produce a working device. Several claimed that they had managed to make the device function at one point, but had since made an adjustment or revision, which prevented it from working.

Many of the students had worked diligently to produce devices that had all of the necessary parts of a Stirling engine in the correct arrangement. Few functioned however, as a result of problems involving the scale of critical components, frictional losses in the system exceeding the power generation potential or difficulties associated with making the cylinder air-tight (or nearly so.)

In a few isolated but noteworthy cases, student groups had made critical design decisions that revealed a fundamental lack of understanding of the principles that allow such a device to operate. These and more subtle design flaws encouraged a discussion of the major challenges in building a Stirling Engine and less formally provided some feedback about the general level of understanding with the course material presented thus far – and what topics may require further attention.

Given the poor showing of working engines at the first review, the project could not progress as originally intended. Rather, students that had produced a working engine were still afforded the opportunity to make revisions prior to the final review to improve the efficiency of the engine and compete for the most efficient device. Those who had failed to produce a functional model could chose between continuing work on their existing device to make it functional or producing a detailed written report and analysis of the proposed design.

At the final review, five teams of the twenty-two had managed to produce a functional engine. Some of these models were exceptionally well produced and showed a great deal of creativity and a firm understanding of both the engine cycles and the principles of heat transfer. The remaining student groups elected to provide only a written analysis of their attempted design.

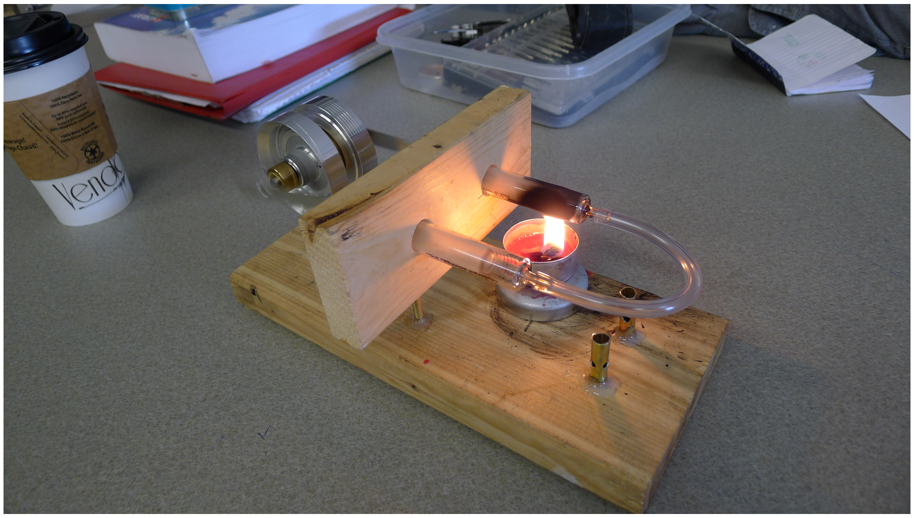

Figure 1. A successful Stirling engine using recycled laboratory equipment and salvaged hard drive parts.

Figure 2. Another successful Stirling engine using a candy tin and parts salvaged from a machine shop, with attention given to dissipating heat from the 'cool' side of the cylinder.

OPEN QUESTIONS AND FUTURE WORK

Perhaps the most interesting finding of this initial trial is a minor detail of the original paper. It appears to be critical that students demonstrate to themselves that they are capable of assembling and creating a working Stirling engine in class using instructions and materials provided by the instructor before they are willing to embrace the risk associated with the production of their own device. No amount of evidence, from lectures or online, indicating that simple working devices can be built to the criteria with easily procured materials seems sufficient to overcome the frustration associated with building and troubleshooting engines of their own design.

In his 2012 paper, Meyer notes that the design and fabrication of a working Stirling engine hinges on the individual's ability to produce a functioning displacement cylinder to reasonably high tolerances [1]. Most of the frustration experienced by the students was caused by a lack of positive feedback as they were developing the device. Results tend to be binary – either the engine will work, or it will not. There is little to indicate that a design was nearly operational or that progress was being made if the issue was with this central device. This likely contributed to an overall feeling of helplessness and that the project was interminable and ultimately the abysmal level of completion observed with the project during this initial run. Providing this component then, may go a great distance to relieving this anxiety and establishing a feeling that the project can indeed be completed even if it is done so with a relatively uninspiring solution.

The failure of some students' ability to grasp the principles that allow the Stirling Engine to operate, demonstrated by poor material choice or other fundamental design flaws, might indicate that interim design reviews would be helpful. In addition to providing an opportunity for further discussion about these principles and their direct application to the project, it may also ensure that students work to a reasonable timeline, avoiding the inevitable sprint and attempts to complete the project in the hours before the final submission is due.

Finally it is worth noting that an overall risk aversion, noted in the author's previous work, wherein students avoid investing time on a project to devise an innovative solution to the proposed design problem out of a fear of achieving a low grade[2] may again have presented itself. In this initial trial, most students elected to complete a computationally heavy theoretical modeling exercise rather than persevere with the fabrication of a working device. This runs counter to a stated preference for working with real materials and designing working things and would seem to indicate an actual preference for completing a traditional written assignment with a definite end, however tedious.

A second iteration of the course has been scheduled for fall of 2015, in which this design project will again be assigned with the revisions noted above. Upon presenting the basic mechanics and analysis associated with a Stirling engine, students will be required to build a working device in class with materials provided. Given the option of using a pre-made displacement and power cylinder arrangement, students will then be required to produce an optimized working design of their own, and provide an brief design report outlining the design revisions and analysis techniques used in the development of the final submission.

REFERENCES

Meyer, E.K. (2011). Rain-dancing with pseudo-science. *7. International CDIO Conference. 2011. p. 292-299.*

Millen B., & McDonald, C. (2014). A Failed Attempt at Teaching Continuously Evolving Software. *Proceedings of CEEA 2014*, Canmore AB.

BIOGRAPHICAL INFORMATION

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