

Enhancing Connection between Theories and Engineering Practices by Designing and Manufacturing Miniature Stirling Engines

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ABSTRACT: *A senior capstone project course is developed and described in this report. This course is designed based on a concept different from most of the existing courses in the traditional curriculum. The overall idea is that students should have a chance to apply all the skills they have learned in the curriculum toward the completion of making a real machine. As a result, the knowledge that they have learned earlier in a more theoretical way may be reinforced in practical applications. Through the training of the course, students have already been educated with the creative, organizational and professional skills needed for successful engineering design. It has been observed that by going through the design and manufacturing process of a small by unique miniature Stirling engine for each individual, the students' lack of design capability and creativity and poor understanding of manufacturing process can be significantly improved.*

1 INTRODUCTION

Engineering curricula and teaching methods in mechanical engineering department appear to lead to weak connection between engineering theories and practical applications, despite the students' lack of design capability and creativity. Enhancement of the linkage between theory and practices is currently one of the major concerns of the engineering educators. A senior capstone project course is developed and described in this report. This course is designed based on a concept different from most of the existing courses in the traditional curriculum. The overall idea is that students should have a chance to apply all the skills they have learned in the curriculum toward the completion of making a real machine. As a result, the knowledge that they have learned earlier in a more theoretical way may be reinforced in practical applications. Through the training of the course, students have already been educated with the creative, organizational and professional skills needed for successful engineering design.

The senior capstone project course is a required course for undergraduate degree at the Department of Mechanical Engineering (DME), Tatung University (TTU). It offers students the opportunity to integrate their knowledge of the undergraduate mechanical engineering curriculum by implementing a concept developed by students and their faculty advisor. All DME students of Tatung University are required to carry out a senior capstone project and file a final report to the Department before graduate. At least two and at most six credits, depending on the students' performance, must be taken before the end of the semester during which the requirements for the degree are completed. Therefore, no later than the end of the second semester of a student's junior year, every DME student must file with his or her faculty advisor a capstone project proposal or give a oral report specifying the title of the capstone project, timeline, research methodology, and the number of credits of capstone project courses to be completed.

As one of the faculty advisors involved in the senior capstone project course, the author has proposed this project to help the students apply thermodynamics, CAD/CAE, machine tool skills, and integrated design methodology for the design, analysis, and manufacturing process, using the miniature Stirling engines as a platform for several years (Cheng, C.H., 2002). In the course, the Stirling engine is used as a platform to carry out the idea. The students have a chance to learn how to use different kinds of computer-aided design and manufacturing (CAD/CAM) tools in the development of a practical engine. It has been observed that by going through the design and manufacturing process of a small by unique miniature engine for each individual, the students' lack of design capability and creativity and poor understanding of manufacturing process can be significantly improved. The students are absolutely excited and encouraged by the active motion of the machines, which were made on their own. It is also

interesting to find that the excitement from the success of an original design eventually leads to more new and novel designs. In this report, the progress achieved in this senior capstone project is updated, and the focus of the continuation of the project is also discussed.

2 STIRLING ENGINES

Stirling engines are power machines that operate over a closed, regenerative thermodynamic cycle, with cyclic compression and expansion of the working fluid at different temperature levels, as described in [Walker, G., 1980]. The working medium is typically air, nitrogen, or helium. The Stirling engines are generally classified into three types of configuration as follows [Ross, A., 1993]:

- α configuration– This type of configuration features two pistons, each in its own cylinder.
- β configuration– This type of configuration has a piston and a displacer in the same cylinder.
- γ configuration– This type of configuration has a piston and a displacer, each in its own cylinder.

The double-acting configuration has multiple cylinders and elongated power pistons, and can be considered as coupled α engines with thermodynamic cycle taking place between the top of one piston and the bottom of the next piston. Liquid-piston engines can be considered to be a special type of α configuration.

There are several advantages associated with the Stirling machines:

- The Stirling machines are of high thermal efficiency.
- A variety of heat sources can be utilized.
- The machines are low in atmospheric and thermal emissions and quiet.

Stirling engine technology has come a long way in the past several decades. However, new concepts and designs continue to appear according to the review of [Ross, B., 1995]. Among all, the domestic-scale Stirling electric power generator is particularly of great market potential [Berchowitz, D.M., 1983].

In addition, care and craftsmanship has gone into the manufacture and assembly of the miniature Stirling engines. Using modern manufacturing technology, parts of these miniature Stirling engines may be machined to tolerances within two thousandths of an inch, then carefully handfitted to assure high performance and long life. These miniature Stirling engines can attain speeds of one thousand rpm on a minimum of heat consumed as described by [Ross, A., 1993] and hence, lend themselves to be a suitable learning device for the students of mechanical engineering.

3 CONNECTION BETWEEN THEORIES AND ENGINEERING PRACTICES

In 1990, a Brigham Young University faculty team of R.H. Todd, S. Magleby and C. Sorensen surveyed industrial companies that hire new engineering graduates. Part of the results of the survey pointed out perceptions of weaknesses in newly graduated engineers.

- No understanding of manufacturing process
- A desire for complicated and "high-tech" solutions
- Lack of design capability and/or creativity
- Lack of appreciation for variation
- All want to be analysts
- Poor perception of the engineering process
- Narrow view of engineering disciplines
- Don't want to get hands dirty
- Consider manufacturing work as boring

To address these weaknesses, author developed the Stirling capstone project. As already stated earlier, this course is designed to guide the senior students in the application of thermodynamics, CAD/CAE, machine tool skills, and integrated design methodology for the design, analysis, and manufacturing process, by using the miniature Stirling engines as a platform.

Progress of the Stirling capstone project at DME, TTU, is illustrated in Table 1. This capstone project was started in the fall of 1995 with only 1 phase of training (manufacturing). This year (the ninth year of operation), there are 4 phases (design, analysis, manufacturing, and performance test) in the training program in operation. During the past eight years, overall 14 students have been involved in this project. On the other hand, this project brings together the machine tools and commercial software needed in all the training phases. The tools employed are shown in Table 2. The students involved in this project are

required to learn how to apply all these tools in different training phases. To complete his or her project, each student must learn to know:

- (1) How to draw a miniature engine with a CAD software, such as PRO/E or SOLIDWORKS.
- (2) How to analyze thermal performance of the engine, including finding out temperature and thermal stress distributions within solid materials with a CAE software, such as ANSYS or COSMOS.
- (3) How to make all the parts of the engine designed by himself or herself and then assemble the engine.
- (4) How to measure the performance of the engine.

In other words, the students are encouraged to use their creativity and have to get hands dirty in all training phases.

The Stirling capstone project needs two semesters (eight months) plus a summer vacation (two months) to complete. A brief schedule for the course is given in Table 3

Table 1. Development of the project

Year	Training phase	Student number
1995-1996	M	1
1996-1997	M, P	2
1997-1998	M, P	4
1998-1999	D, M, P	6
1999-2000	D, A, M, P	8
2000-2001	D, A, M, P	10
2001-2002	D, A, M, P	12
2002-2003	D, A, M, P	14

D: Design A: Analysis M: Manufacturing
P: Performance test

Table 2. Tools integrated in the course

Training phase	Tools
D	SOLIDWORKS, PRO/E, NASTRAN DESKTOP, etc.
A	ANASYS, COSMOS, etc.
M	Machine tools (lathe, drilling, milling, etc.)
P	Power measurement, data acquisition system

D: Design A: Analysis M: Manufacturing P: Performance test

Table 3. Schedule of the course

Month	Stage	Training phase
1 ~ 3	Preliminary design	D
3 ~ 4	Analysis and re-design	A and D
4 ~ 8	Machining and Assembling	M
8 ~ 9	Performance test	P
9 ~ 10	Refinement	D, A, M, and P

D: Design A: Analysis M: Manufacturing P: Performance test

4 RESULTS AND EVALUATION

Figure 1 shows a part of the students' report for a typical case to clarify the concepts and goals in different training phases. Height of this miniature engine is 18 cm. When heated by a heat source of approximately 350°C, it is capable of attaining speed of 300 rpm.

Note that to fulfill a same required mechanical motion, different structures may be created by different students. Figure 2 displayed three mechanical designs for a β -configuration Stirling engine, including rhombic-, grooved-shaft-, and cam-drive structures. These three designs feature similar relative motions between the displacer and the piston.

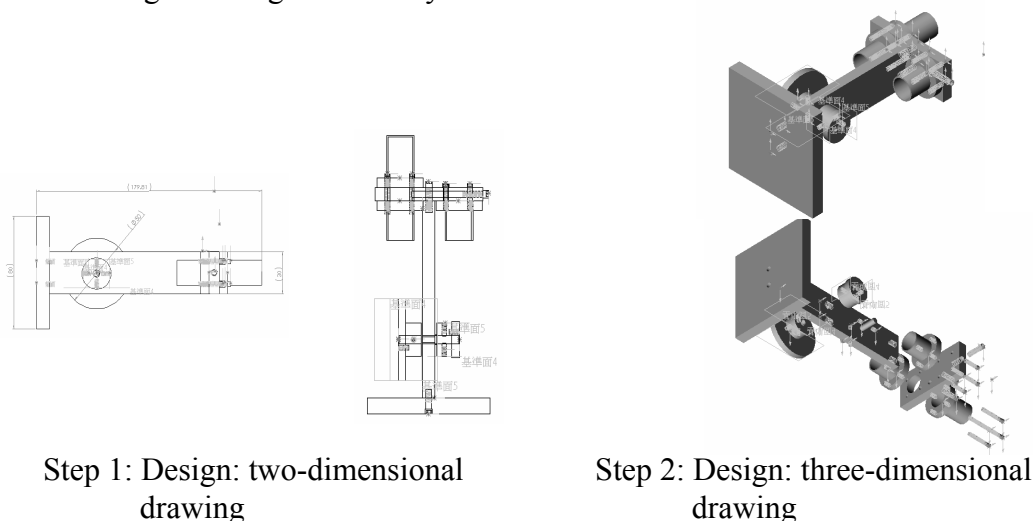
In the past eight years, it has been observed that the weaknesses of the DME students in creativity and manufacturing may be significantly strengthened by a carefully designed capstone project. For example, through the design phase of this capstone project, the students' lack of design capability and creativity is greatly improved since they are able to design a machine that they can really make by themselves. In this way, poor understanding of manufacturing process can also be improved since the students will have a chance to use all kinds of machine tools during the later manufacturing phase. Theories and analytical methods of thermodynamics or material mechanics become 'visible' and not boring any more during the analysis phase. Eventually, the students are absolutely excited by the motion of a living machine, the Stirling engine, which was made by themselves. In this manner, the knowledge that they have learned earlier in a more theoretical way may be reinforced in practical applications. Through this project, students have already been trained with the creative, organizational and professional skills needed for successful engineering design.

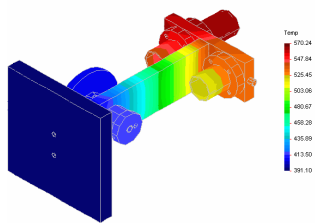
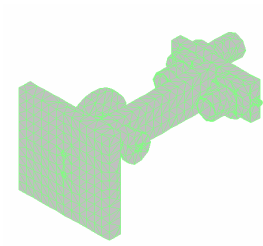
Figure 3 shows a number of examples which were designed, manufactured, and assembled by the senior students involved in this project.

It is important to note that the training methodology is general and not limited to the applications related to the Stirling engine design. Meanwhile, to achieve collaborative learning by combining education and industry even at the undergraduate level, the project is currently in collaboration with a local company. Faculty and the sponsoring company involved with the project continue to give the project high marks for helping students learn the practice of engineering.

5 CONCLUSIONS

A senior capstone project course is developed and described in this report. The overall idea of the course is that students should have a chance to apply all the skills they have learned in the curriculum toward the completion of making a real machine. In the course, the Stirling engine is used as a platform to carry out the idea. The students have a chance to apply different kinds of computer-aided design and manufacturing (CAD/CAM) tools in the development of a practical engine. It has been observed that by going through the design and manufacturing process of a small but unique miniature engine for each individual, the students' lack of design capability and creativity and poor understanding of manufacturing process can be significantly improved. The students are absolutely excited and encouraged by the active motion of the machines, which were made on their own. It is also interesting to find that the excitement from the success of an original design eventually leads to more new and novel designs.





Step 3: Analysis: mesh and FEM analysis

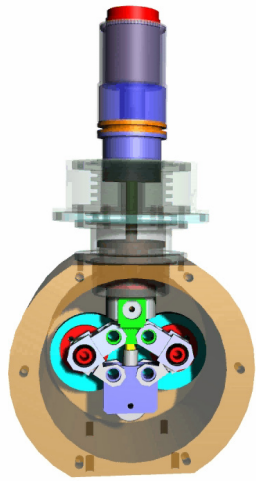


Step 4: Manufacturing: making all the parts by machine tools

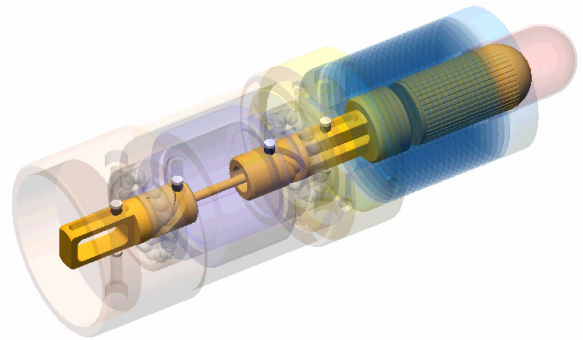


Step 4: Performance test: assemble and performance measurement

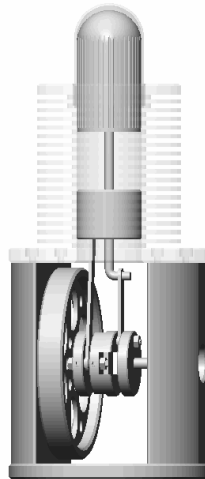
Figure 1. A typical final report of student work



(a) Rhombic-drive structure



(b) Grooved-shaft-drive structure



(c) Cam-drive structure

Figure 2. Mechanical designs for a β -configuration Stirling engine.

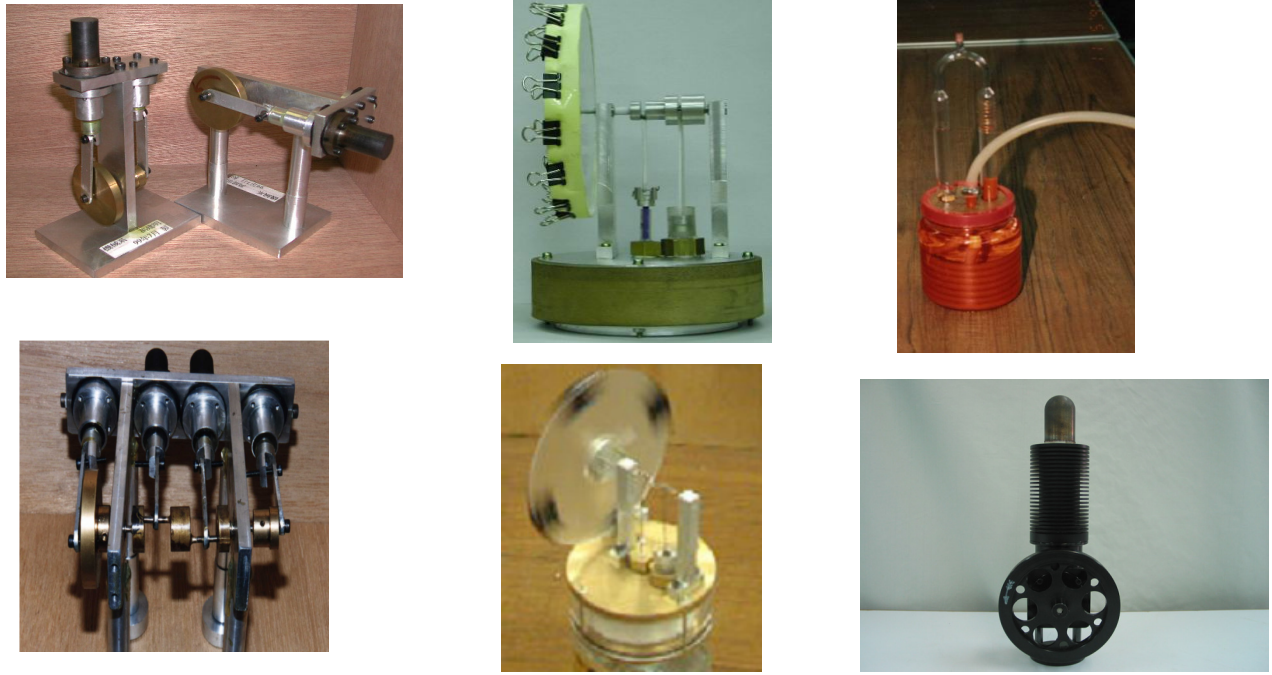


Figure 3. Examples of the students' works.

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