SIX-YEAR EXPERIENCES ON A SENIOR CAPSTONE PROJECT INTEGRATING DESIGN, ANALYSIS, AND MANUFACTURING OF THE MINIATURE STIRLING-CYCLE ENGINES

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Abstract *— In this report, six-year experiences on a senior capstone project are presented. This project is designed to guide students in the application of thermodynamics, CAD/CAE, machine tool skills, and integrated design methodology for the design, analysis, and manufacturing process of the miniature Stirling engines. The project is different in flavor and concept from most of the existing courses in the curriculum in that it is focused primarily on the continuous improvement of the engine design. The overall idea is that each student should have a chance to apply all the skills he or she has learned in the curriculum toward the completion of making a real machine. Thus, this course has the effect of reinforcing concepts that have been learned earlier in a more theoretical way. Through this project, students have already learned with the creative, organizational and professional skills needed for successful engineering design.*

Index Terms *— Capstone project, Stirling engine, Creativity, Design.*

DEVELOPMENT OF CAPSTONE PROJECT

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, author 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.

This project is designed based on a unique concept different from most of the existing courses in the curriculum. It is focused primarily on the continuous improvement of the miniature engine design. 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 this project, students have already been trained with the creative, organizational and professional skills needed for successful engineering design.

MINIATURE STIRLING ENGINES

Strrling 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 [1]. The working medium is typically air or helium. The Stirling engines are generally classified into three types of configuration as follows [2]:

- 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 [3-5]. However, new concepts and designs continue to appear [6]. Among all, the domestic-scale Stirling electric power generator is particularly of great market potential [7].

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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 and hence, lend themselves to be a suitable learning device for the students of mechanical engineering [2].

DESIGN, ANALYSIS, MANUFACTURING, AND PERFORMANCE TEST

In 1990, a Brigham Young Univerity 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 adress 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 I. This capstone project was started in the fall of 1995 with only 1 phase of training (manufacturing). This year (the seventh year of operation), there are 4 phases (design, analysis, manufacturing, and performance test) in the training program in operation. During the past six years, overall 10 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 II. 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, 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 summar vocation (two months) to complete. A brief schedule for the course is given in Table III.

TABLE I
PROGRESS OF STIRLING CAPSTONE PROJECT

Year	Training phase	Overall 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)

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

TABLE II
TOOLS EMPLOYED

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

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

TABLE III
SCHEDULE OF STIIRLING CAPSTONE PROJECT

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

RESULTS AND EVALUATION

Figures 1 to 5 show part of the students' reports for a typical case (α configuration two cylinder Stirling engine) 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℃, it is capable of attending speed of 300 rpm.

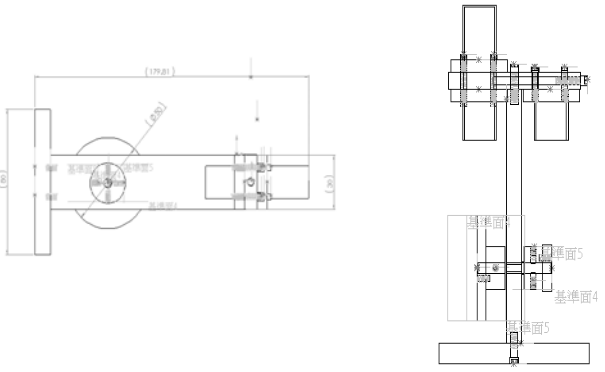


FIGURE. 1
DESIGN PHASE: TWO-DIMENSIONAL DRAWING.

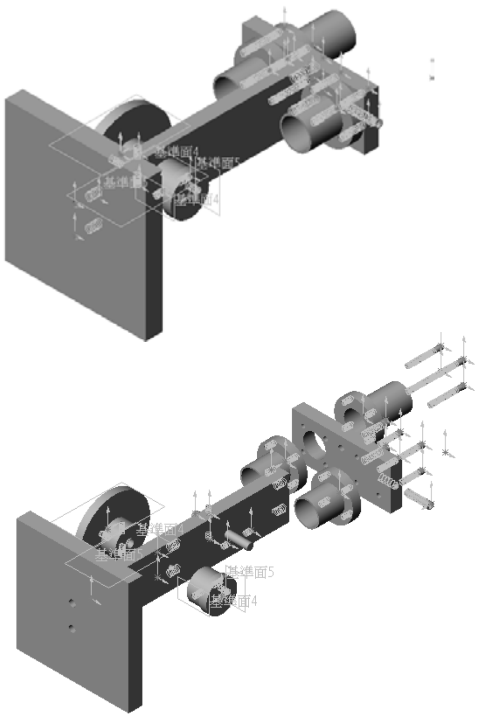


FIGURE. 2
DESIGN PHASE: THREE-DIMENSIONAL DRAWING (D) USING CAD TOOLS (SOLIDWORKS).

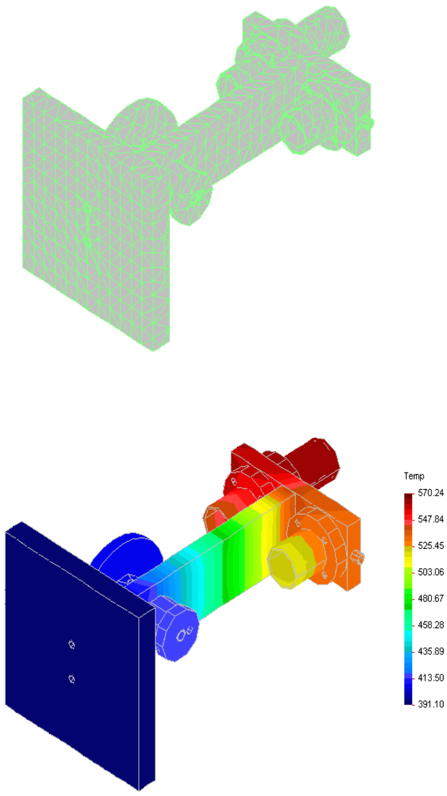


FIGURE. 3
ANALYSIS PHASE: MESH AND FINITE ELEMENT ANALYSIS FOR TEMPERATURE AND THERMAL STRESS DISTRIBUTIONS USING CAE TOOLS (COSMOS).

FIGURE. 4
MANUFACTURING PHASE: MAKING ALL THE DESIGNED PARTS BY MACHINE TOOLS.

FIGURE. 5
PERFORMANCE TEST PHASE: ASSEMBLE AN ENGINE AND MEASURE ITS PERFORMANCE. [THE ENGINES SHOWN WERE MADE BY M.S. TSAI (1998) AND C.M. WAN (1999).]

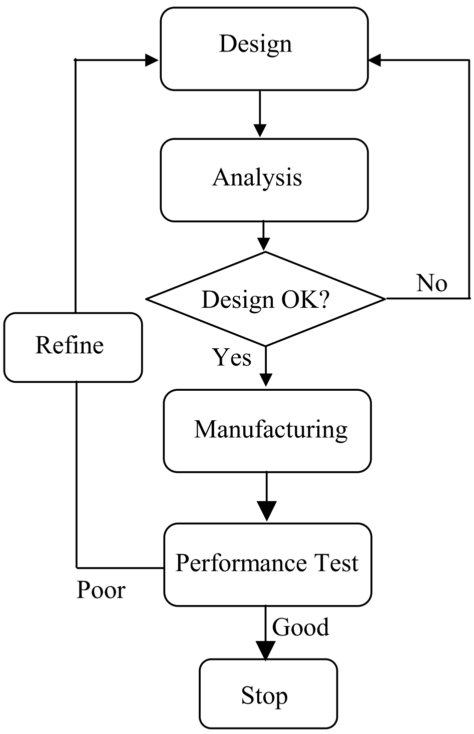


FIGURE. 6
FLOW CHART OF THE STIRLING CAPSTONE PROJECT

Figure 6 displays the flow chart of the Stirling capstone project. Note that refinement for the work is encouraged but not required in this project. However, it is interesing to find that almost all the students would like to improve their works next to the performance test.

In the past six 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 themself. 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 materical mechanics become 'visible' and not boring any more during the analysis phase. Eventually, the students are absolutely excited by the motion of a living macine, the Stirling engine, which was made by themself. 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.

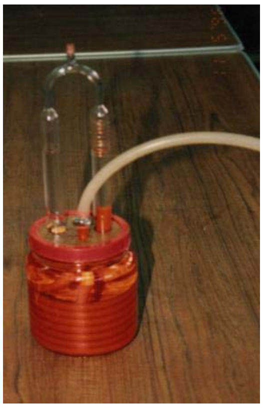
Figure 7 show several other examples which were designed, manufactured, and assembled by the senior students involved in this project.

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.

CONCLUDING REMARKS

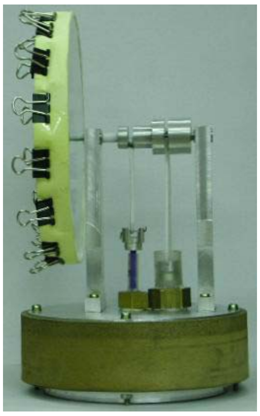
As a part of the senior capstone project course at Department of Mechanical Engineering, Tatung University, the project presented in this report has been developed to guide students in the application of thermodynamics, CAD/CAE, machine tool skills, and integrated design methodology for the design, analysis, manufacturing, performance test for the miniature Stirling engines. The overall idea is that the students should have a chance to apply all the skills they have learned in the curriculum toward the completion of making a real machine.

During the past six years, it is found that the weaknesses of the DME students in creativity and manufacturing may be significantly strengthened by a carefully designed capstone project. Students need to know that they are able to design and manufacture a machine by themself.



(A) A STIRLING FLUIDYNE PUMP MADE BY F.L. LIAO (1996)
(THIS PUMP IS DESIGNED BY A.E.R.E. HARWELL [2].]

(B) α CONFIGURATION FOUR CYLINDER/ONE CRANKSHAFT HORIZONTAL STIRLING ENGINE MADE BY C.M. WAN (1999).



(C) γ CONFIGURATION VERTICAL STIRLING ENGINE DRIVEN BY LOW TEMPERATURE DIFFERENCE MADE BY C.J. SHIE (2001).

FIGURE. 7
WORKS MADE BY THE STUDENTS

REFERENCES

[1] Walker, G., *Stirling Engines*, 1980, Chap. 1, 1980, Oxford, New York.

[2] Ross, A., *Making Stirling Engines*, 1993, Ross Experimental.

[3] Wurm, J., et al., *Stirling and Vuilleumier Heat Pumps*, 1990, McGraw-Hill, New York.

[4] Hargreaves, C.M., *The Philips Stirling Engine*, 1991, Elsevier, New York.

[5] Walker, G. and Senft, J.R., *Free Piston Stirling Engine*, 1985, Springer-Verlag, New York.

[6] Ross, B., "Status of the Emerging Technology of Stirling Machines," *IEEE AES System Magazine*, June 1995.

[7] Berchowitz, D.M., The Development of a 1 kW Electrical Output Free Piston Stirling Engine Alternator Unit, The 18th Intersociety Energy Conversion Engineering Conference, Orlando, Florida, 1983, pp.897-901.