Mechanical Engineering Practice – using a simple Stirling engine as case

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ABSTRACT

The first technical course that students in mechanical engineering take at the Technical University of Denmark is called “Mechanical Engineering Practice”. We have used a simple Stirling engine as a design-implement project. Students were asked to design and build a heat engine using materials obtained by their own means and were competing on achieving the highest efficiency. We added an extra dimension to the project by making detailed measurements of the pressure variation to check simple thermodynamic models of the engine. The course had integrated lessons in sketching and technical drawing. The Stirling engine worked well in the drawing assignments. The Stirling engine also served as illustration of coming courses in mechanical engineering. The resulting engines had large variations in their design and most groups succeeded in building a functioning engine. However, achieved efficiencies were quite low.

KEYWORDS

Stirling engine, design-implement, design-build-test, first-year course.

INTRODUCTION

The Bachelor program in Production and Engineering Design (in Danish: Produktion og Konstruktion) is a three year program that represents classical mechanical engineering education at the Technical University of Denmark. Almost all students continue on a master program after completing their bachelor. The bachelor program is not designed as a CDIO education and therefore does not formally implement the CDIO syllabus. However, a few mandatory courses try to implement CDIO ideas. One example is the course in Mechanical Engineering Practice given on the first semester together with two general courses in mathematics and physics. The course in Mechanical Engineering Practice is the first course where the students meet topics specific to mechanical engineering.

It is common that introductory first-year courses include basic design-implement experiences [1]. These are sometimes called “design-build-test” projects. Popular topics are building model vehicles [2] or model aircrafts (“design-build-fly”) [1]. Other examples are building a Vertical Axis Wind Turbine [3] or a crane [4]. A comparison of many first-year design-implement projects was done by [5]. They found a high level of consistency across different institutions with most projects being done in small teams and with emphasis on practical sessions with a limited number of lectures and modest amount of faculty and money support.

It is common for design-implement projects to involve a competitive element to motivate the students. The competition should be on a parameter that is easy to determine like who travels the longest distance or achieves the largest power.

As discussed in [1], a design-implement project has multiple purposes. Besides being a motivating activity, it teaches students personal and interpersonal skills, strengthens the learning of material also presented otherwise and simulates professional engineering practice. Finally, for a first-year project, an important goal is to gain a deeper understanding of different engineering disciplines before selecting later courses to follow. At the Technical University of Denmark, students only have few mandatory courses and instead select courses in different categories. This makes it particularly important to give the students a background for making course selection later.

When selecting a problem for a design-implement project, there are several things to take into account. The course resources both in terms of cost of materials, laboratory space and faculty time per student are limited. The problem should have simple solutions so that all students have a good change of creating one, but at the same time, the problem should offer plenty of challenge and enough complexity to simulate professional engineering practice. We suggest in this paper to use a simple Stirling engine as the problem.

COURSE OBJECTIVES AND CONTENT

The course in Mechanical Engineering Practice gives a credit of 10 ECTS point and is given during a 13 week period. The course is given for a full day every week. The afternoon is for most days used for lessons in sketching and technical drawing. In addition, the course has extraordinarily been assigned two hours an afternoon on a different weekday for extra lectures and presentations. The 10 ECTS point correspond to a total workload of 280 hours. This means that students are expected to work at home or in the workshop outside class hours.

Important objectives for the course are to:

- Introduce students to life as a university student
- Introduce students to core topics in mechanical engineering like solid/fluid mechanics, production technology, thermodynamics and materials with the main purpose of supporting selection of future courses.
- Give students an experience in developing a simple mathematical model of a product to analyse forces and thermodynamics.
- Let students practice construction and product analysis in groups.
- Give students some first experience in laboratory work, practical construction and measurements
- Teach three-dimensional sketching, technical drawing and Computer Aided Design (CAD).
- Let students document and present results in technical reports and through oral presentations.

As the course was given this time, about 40% of the course was given as regular lessons in sketching, technical drawing and CAD. About half of the course was a design-implement project that involved core topics of mechanical engineering as mentioned above. Teachers of coming courses in core topics in mechanical engineering were invited to give short presentations of their topic with examples applied on the design-implement project and followed by a question-and-answers session where students could get advice on their project. The course had a few other elements like a talk by an experienced engineer, visits to two companies and presentations by older students advicing on studying routines.

A new objective that we wanted to test in the course was to let students make measurements on their construction to test their mathematical model of the construction. Many of the first-year design-implement projects mentioned earlier basically only do measurements on the single parameter like travelled distance used in a competition. We wanted to make more detailed measurements to test details in the models. This is obviously more complicated, but it creates a much stronger link between theory and practice. It is possible to get simple and cheap measurement systems that can be handled and changed by the students. A typical solution is to use USB-based acquisition hardware together with the LabView software.

STIRLING ENGINE AS CASE

We have explored using a simple Stirling engine as a case for a first-year design-implement project. A Stirling engine is a heat engine that works on a gas in a closed system where the gas typically is moved between two cylinders with pistons. The most convenient design for a student project is the so-called "Gamma" configuration operating with air as medium. This design has a cylinder with a hot end heated by a flame and a cold end cooled by the surroundings. The air is moved by a piston (displacer piston) between the hot and cold ends. This changes the pressure in the closed system. A second cylinder is connected to the first cylinder. Here a piston (power piston) makes expansion and compression strokes extracting mechanical energy from the system.

A simple Stirling engine has a number of properties that make it well-suited for a design-implement project:

- A functional engine can be build using cheap materials and simple tools
- There is a huge solutions space both in terms of fundamental configurations and in selection of parameters and materials. This makes it a good simulation of professional engineering practice
- Most disciplines within mechanical engineering are involved in the design of a Stirling engine
- Students can make a mathematical model based only on geometry and the ideal gas law and get fair agreement with measurements
- The engine has a level of detail that makes it suitable as a final assignments for sketching and technical drawing
- It is very motivating for students (and for some surprising) that they can build something that moves by itself

The first challenge is to get an engine that runs at all. The most important factor is to make the engine reasonably airtight and at the same time have low friction for piston movement. This gives a basic insight in machine elements and manufacturing tolerances. Further optimization of the efficiency is typically related to selection of size of air volumes, pressure drop in channels and heat resistance in different places. Here simple models and estimates provide important help. When speed increases with optimization, component strength and machine dynamics becomes important. All these parameters link mechanical engineering disciplines to the project.

There is plenty of material on hobby Stirling engines on the internet. An example is a large amount of videos found when searching for "Stirling Engine" on youtube.com. These serve as inspiration for students when designing their own engine. Sorting out what is actually going on in videos or whether an explanation of a principle is plausible, is a good exercise in the process of doing one's own design.

The students can manufacture most of the engines components themselves by simple means, but will discover that a few key components have higher requirements for tolerances and manufacturing technique. They therefore learn to appreciate help from professional technicians on these key components.

Finally, we were fortunate to have a start-up company on the university campus that manufacture biomass fuelled Stirling engines (Stirling DK, www.stirling.dk). A visit to this company and discussions with engineers from the company was a great motivation for the students.

COURSE STRUCTURE AND ASSIGNMENTS

We organized the course around a competition: “Make a machine than converts heat from a flame to mechanical energy on a shaft”. The main price was given to the engine that demonstrated the highest energy efficiency. Other prices were given for original design and best analysis/documentation. Finally, we had a fighter price for a group that tried an unconventional solution. The competition had a few extra restrictions: the cold end had to be cooled to the surrounding air; the engine had to be tested under steady conditions and no other consumables than the fuel for the flame could be used. This ruled out building a simple steam engine or cooling the engine with ice. The engine should be manufactured by components that the students obtained by their own means. However a few components could be manufactured by technicians in our workshop if the students provided a correct technical drawing. The students were divided into groups of 4 persons that worked together for all assignments in the course. About 65 students participated in the course.

Figure 1. Stirling engine built by students on first day of the course.

To get students convinced that they were able to build a Stirling engine, they were given parts and instructions to build a first engine on the first day of the course. The main components where a tin can, a balloon, a Compact Disc, a short plastic pipe and some pieces of wire, wood and plate – see figure 1. A brass fitting for guiding a wire holding the piston in the tin can was made in advance by the workshop and mounted on a circular plate. Some other pieces of plate were also cut and prepared. This was done to save time on the first day. The engine could run on a small candle. Figure 2 shows students building this engine. Nearly all groups got a running engine within a few hours of work.

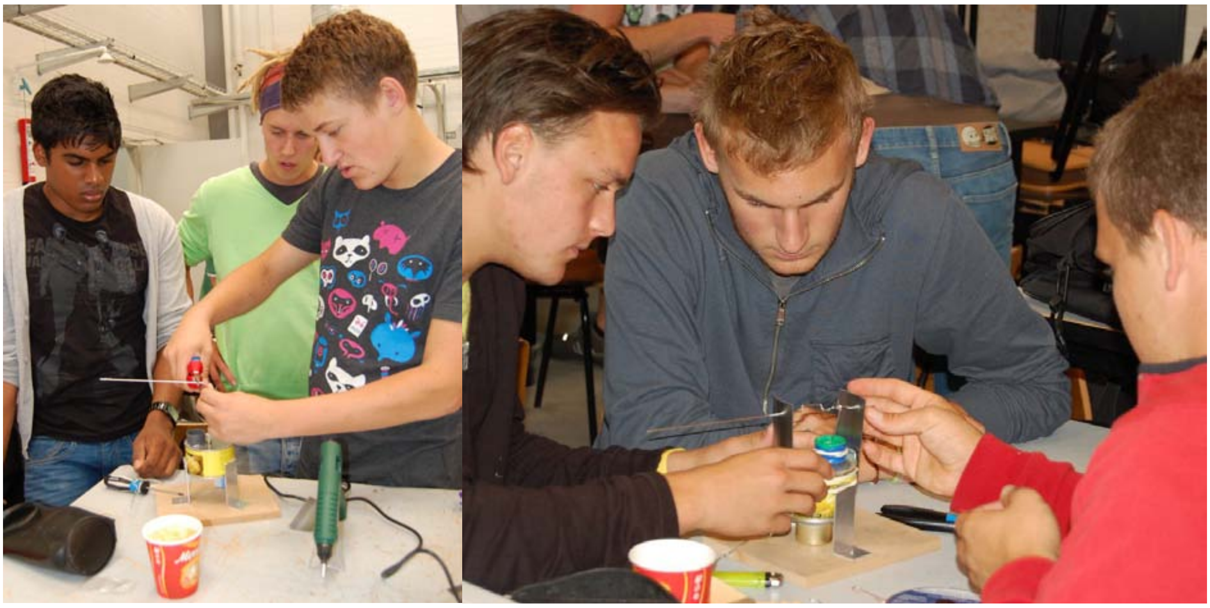

Figure 2. Two groups building a “tin can” engine on the first day of the course.

The second assignment was to model different aspect of a transparent Stirling engine. The engine was a commercial design for educational purposes (model GT03 from Stirlingshop.de), see figure 3. We instrumented this engine with a pressure measurement in the power piston cylinder, temperature measurements of hot and cold ends of the main cylinder and support for simple measurements of the shaft torque. Students were given a few lectures on modelling of forces, strength of a rod, how to model thermodynamics using the ideal gas law and how to estimate pressure drop in channels. Students were asked to make a short technical report showing model calculations and comparing to observations. The thermodynamic model gave an estimated power that was twice the observed power. Students were supposed to argue that the main reason for this difference was friction and pressure losses.

Figure 3. Transparent Stirling engine used for second assignment

The final assignment was to construct an engine for the competition. Students were offered a solution for a power piston with an acrylic cylinder and a brass piston with a standard diameter of 27 mm. The power piston is the most critical component with respect to low friction combined with almost airtight operation. More than half of the groups selected this option. The final construction was documented by the group in a technical report and was also presented in a poster presentation with running engines on the last day of the course.

Assignments related to lessons in sketching and technical drawing were given in parallel with the assignments on Stirling engines. Students were asked individually to hand in sketches of ideas for engines considered in their group. Each student was also asked to do a CAD model of the group's final construction. Finally, drawings used in the technical reports were also included in the student evaluation.

EVALUATION AND PLANNED IMPROVEMENTS

The course was in general very well received by the students. They spent many hours constructing their own design and the solutions had a large variation. Examples of solutions are illustrated in figure 4 and 5.

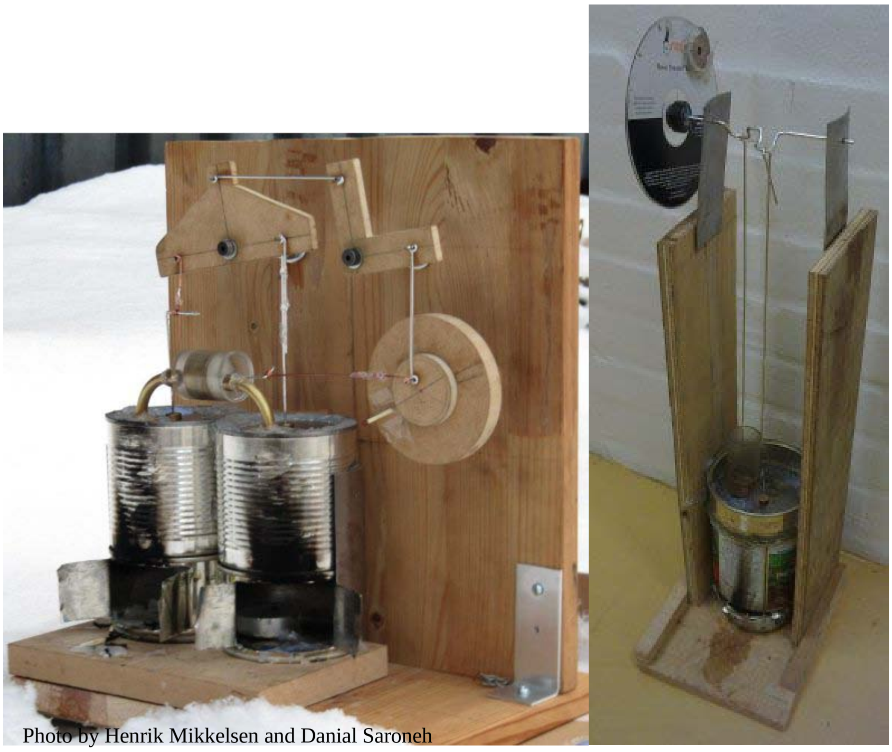

Figure 4. Two examples of successful engines. The engine to the right won the competition on best efficiency.

A few groups did not get their engine running. Some groups did get an engine running, but did not succeed in measuring the efficiency. About half the groups had an estimate of the efficiency and a few groups managed to get detailed measurements of pressure and temperature on their engine, see figure 6. The maximum efficiency (power on shaft divided with fuel consumption) where not impressive with the winning teams solution (see figure 4) having an efficiency of 0.06%.

Many elements of the course were developed on the fly, especially techniques for measurements. It was difficult to predict what kind of engines we could expect the students

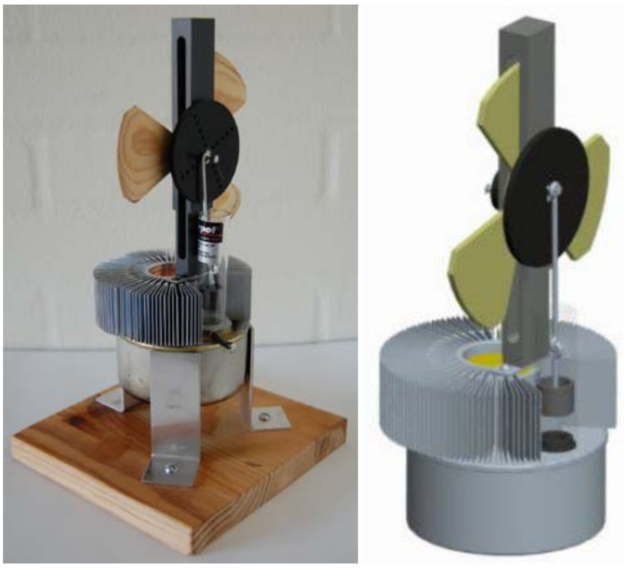
Figure 5. Example of successful engine (left) and the CAD model of the same engine (right).

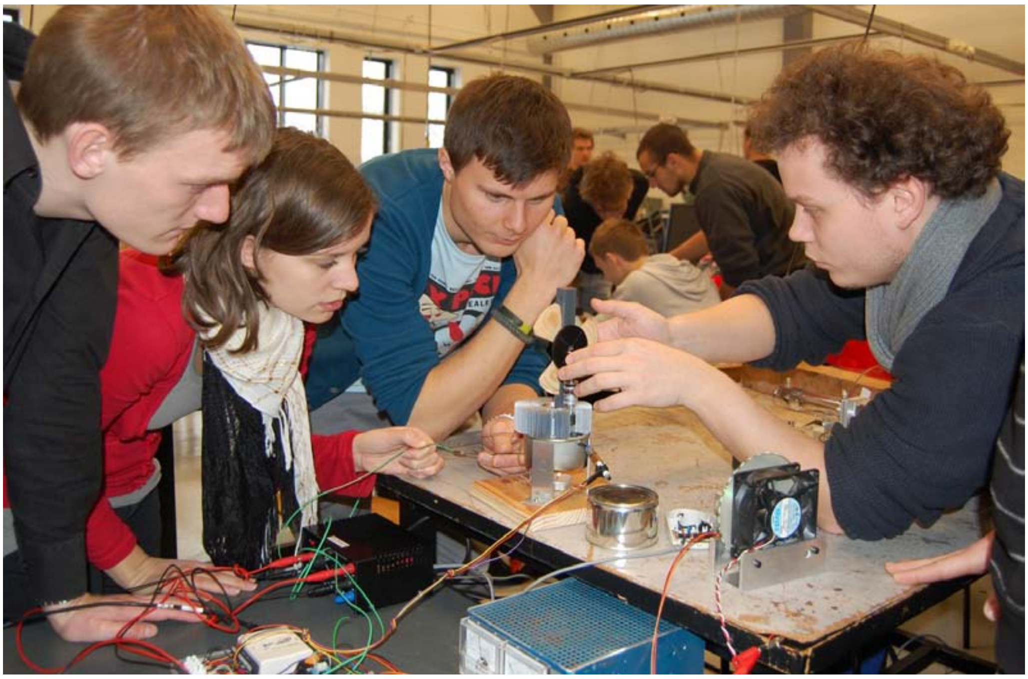

Figure 6. Group during measurements on their own design

to make and therefore also what measurements they could do. Next time, we will introduce measurements earlier in the course to make the students include support for measurements in their design from the beginning. We expect that measurements earlier in the design process will improve the design significantly.

Students were in general very motivated at lectures and were asking many questions. This probably reflects that they realised that topics were important for their project.

Student evaluation of the course was in general positive with 84% of the students in their evaluation of the course agreeing that the course was good or mostly good. We got positive comments like “very motivating to build your own engine”, “hands-on from day one”, “you get a good overview of the later [elective] courses” and “great fun to actually do something in practice”. Several critical comments related to issues around lessons in sketching and technical drawing. This will be organised differently next time the course is given. Another issue raised by several students was the lack of a textbook and course notes. We intentionally handed out only brief material on the physical modelling, since it is a part of the assignment to develop the models from scratch. However, it is important to make this even clearer for the students. Finally, some students complained that lack of time prevented them for getting all things right. Since lack of time for understanding all details is a fact of life for most students, we will make this point even more clear in future versions of the course.

CONCLUSION

We consider the idea of using a simple Stirling engine in a first-year design-implement course a success. Compared to other published first-year design-implement projects like building a vehicle or a wind turbine, the Stirling engine involved more mechanical engineering disciplines, especially thermodynamics. We find it useful integrating detailed measurements to check simple models of the operation of the engine. Evaluations by students and teachers have been quite positive. We plan to use the simple Stirling engine for the first-year students in future courses and expect to improve implementation of the project based on our gained experience.

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Biographical Information

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