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FABRICATION OF STERLING ENGINE

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Abstract: The aim of this project was to design, build, and test a Stirling engine capable of generating between 200-500 watts of electricity. Several designs were studied before settling on an alpha type configuration based around a two-cylinder air compressor. Concentrated solar energy was considered as a potential heat source, but had to be replaced by a propane burner dueto insufficient solar exposure during the testing timeframe. The heater, cooler, regenerator, flywheel and piping systems were designed, constructed, and analyzed. Instrumentation was builtinto the engine to record temperatures throughout the assembly. Several tests were performed onthe engine in order to improve its running efficiency, and critical problem areas were isolated and addressed.

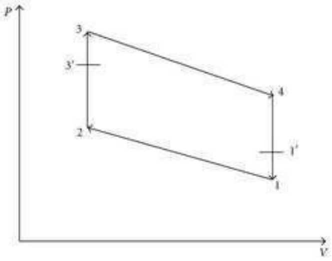
I. INTRODUCTION

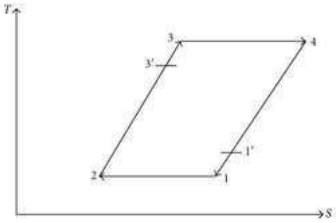
The goal of any engine is the production of useful work. Most modern engines rely on internal combustion in some form to drive pistons and an output shaft. Internal combustion engines suffer from relatively poor efficiency and increasingly complicated electronic and mechanical systems. A Stirling engine avoids these problems. By having the working fluid stayinside the pistons through the entire engine cycle, it provides good operating efficiency, low complexity, and high versatility.

Dr. Robert Stirling developed the true Stirling engine design in 1816[1]. Stirling's *heat economiser,* now known as the regenerator, drastically improved the efficiency of the closed- cycle air engine. The regenerator acts as a heat exchanger between the cold and hot sides of the engine, absorbing heat from the working fluid during the expansion stroke, and returning it during the compression stroke. This process allows

for significant energy savings between cycles. Existing steam and hot air engines at the time could not compensate for this lost heat. The addition of the regenerator allowed the Stirling engine to enjoy a period of unrivaled efficiency. It was also significantly safer to operate than steam engines, as their boilers ran the risk of exploding. Soon,advances in steam engine design, and later internal combustion, eclipsed the Stirling engine in terms of practicality and efficiency. It became much cheaper to produce high-horsepower steam engines because of advances in materials and boiler construction, and internal combustion.

Background:
Stirling engines exhibit the same processes as any heat engine: compression, heating, expansion, and cooling. Stirling engines operate on a closed regenerative thermodynamic cycle. Gas is used as the working fluid, and undergoes cyclic compression and expansion in separate chambers with changing volume. In a typical Stirling engine, a fixed amount of gas is sealed within the engine, and a temperature difference is applied between two piston cylinders. As heatis applied to the gas in one cylinder, the gas expands and pressure builds. This forces the piston downwards, performing work. The two pistons are linked so as the hot piston moves down, the cold piston moves up by an equal distance. This forces the cooler gas to exchange with the hot gas. The flow passes through the regenerator, where heat is absorbed.

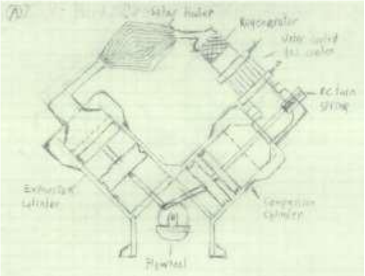




II. METHODOLOGY

Design of the Stirling Engine

Our project began with researching the history and design of existing Stirling engines. While a relatively large hobby building community exists, few designs for engines of practical scale have been proposed. We built a small-scale engine to examine the principles of Stirling engine construction and operation. Our main design inspiration came from an engineer who built an engine to operate in the 500-700 Watt range16. This engine used a propane burner as its heat source. Our design was intended to be more versatile, with the intention of using concentrated solar power as the heat source. One of our goals was to keep the engine easily modifiable, while still maintaining good dimensional tolerances and component compatibility. We decided to utilize as much of the existing air compressor as possible in order to reduce the amount of time needed for construction.



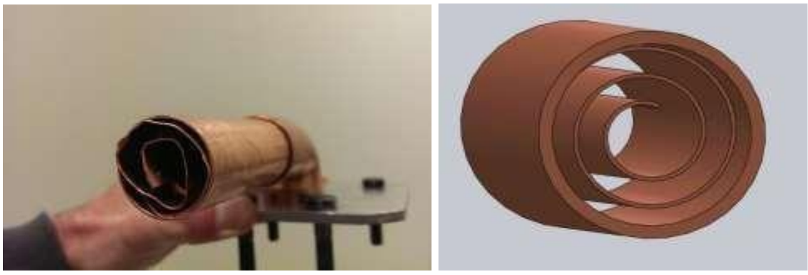
Compressor

A key design innovation was the adaptation of the piston housing of a V-block air compressor into an engine. We considered this a good design choice as opposed to machining our own pistons and housing. Not only would the tolerances required by the design be difficult.

We removed the caps covering both of the pistons in order to investigate how we could convert the compressor into a Stirling engine. Figure 11 shows an internal view of the piston once the caps on the engine were removed. With the removal of the caps and noting the inner workings of the compressor, we concluded that one cap could be used as part of the cooler. the heater would need to be completely rebuilt in order to get the material properties needed. Of the seven boltholes that can be seen in Figure 11, all seven are used to connect the modified cooler cap, while only four were necessary to connect the heater. The oil inside the compressor was alsoreplaced with a 5W-50 motoroil in order to assist the movement of the pistons and reduce the friction inside the pistons and on thecrankshaft.

The regenerator was Dr. Stirling’s principal contribution to the field of hot air engines.The intent of a regenerator in a Stirling engine is to recover as much heat as possible from the aircoming out of the expansion cylinder. As the hot working fluid expands, it flows through the regenerator coil. The coil removes and stores some of the heat from the air before it passes through the cooler. This allows for reduced energy requirements for the cooling of the fluid. Theopposite is true on the return stroke. The regenerator returns the stored heat to the cooled fluid, therefore making the engine import less energy to heat the fluid up again. This regenerative action is the reason Stirling engines have high thermal efficiencies between given temperature limits[17]. Regenerators also have an advantage over other methods because of their high surfacearea to volume ratio, which requires less material to manufacture.

The design of our regenerator focused on maximizing the surface area. Our original design was similar to existing mesh-type regenerator systems. It consisted of a packed mesh ofsteel wool, with a known porosity. However, one of the drawbacks of the regenerator system isthat consistent and turbulent temperature fluctuations can put a lot of stress on the regenerativematerial. Coupled with the pressure of air flowing back and forth, this can lead to significant degradation. Over time, pieces of the steel wool could fall into the piston cylinders and cause damage to the walls. After multiple issues with the steel wool becoming frangible under high heat, the mesh type design was abandoned



Heat Sources

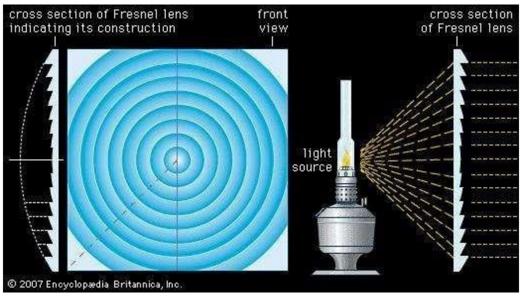
We researched several renewable solutions for providing the heat our engine would require. Our preliminary list included 13 possible heat sources we would potentially tap into.After weighing the pros and cons of each, we decided the Fresnel lens was our best choice. One of the potential heat sources we considered was the parabolic dish. The parabolicdish has the potential to reach temperatures over 200 degrees Celsius.[18] It is also versatile. Depending on the design of the dish, the size of the focus as well as focal length can beoptimized. These are great attributes for a solar collector.

Another possibility was a solar furnace. Similar to the parabolic dish, small-scale versions of the solar furnace can reach over 150 degrees Celsius. While these devices are somewhat commercially available, we were unable to find one that was the right size for ourpurposes. The heat produced in a server room was another possibility. While these rooms usually reach temperatures of only 95 degrees Fahrenheit[19], they produce consistent heat. The consistency is important because the Stirling engine only relies on the differential to produce energy, not necessarily high temperature. This option was eliminated because we did not believeour engine design could generate effective power at those temperatures. We also lacked reliable access to an appropriate testing environment. The waste heat from a commercial deep fryer was also discussed. At the Frito-Lay Plantin Binghamton, New York, they are able to recover up to 160 degrees Fahrenheit from their frying process. [20]However, this is a low grade heat of varying temperature, and would not maximize the effectiveness of a Stirling engine,

Fresnel Lens:

In 1748, Georges-Louis Leclerc de Buffon came up with the idea to create a lens composed of several concentric circles as a way to reduce weight. Sometime later in 1821 this idea was improved upon by Augustin-Jean Fresnel as a way to create lighthouse lenses. [22] Originally, the lens was used to take a small light source and magnify it to go large distances.

Ascan be seen from Figure 20, this was a highly effective technique, and has remained relatively unchanged since its invention. When researching techniques for solar collection the Fresnel lens

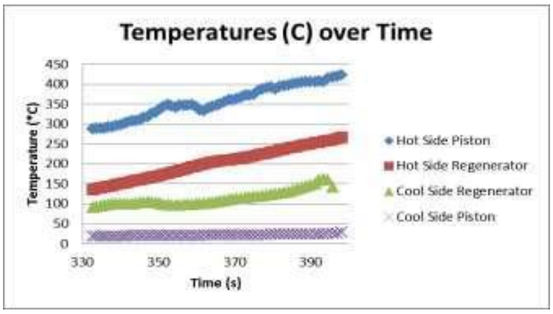


III. RESULTS

While we were able to gather good temperature data from our tests, we were not able to get the engine to run on its own. Repeated attempts to kick start the system, through pull-startingand by continuous rotation with the drill, always resulted in the engine quickly coming to a stop.As the numerical analysis will show, our dead volume was unacceptably high for the low- pressure working fluid. The testing of the engine revealed other significant design flaws, which we addressed. The compressor lacked lubrication, so 5-50 wt. engine oil was added to the crankshaft chamber. Several dead volumes within the compressor were also discovered and filled with expanding foam and JB Weld. Various leaks in the heating and cooling sides of the engine were also observed as we rotated the crankshaft with the drill. Leaks on the cold side were easily fixedwith Silicone gasket sealant, but the hot side proved impossible to fix. Any sealant we applied tothe hot side would have quickly failed under the high temperature of the burner or Fresnel lens. When the engine was turned with a temperature difference applied, it was also observed that the RPM of the engine decreased. Further study of the pressures within the system would be required to determine the source of this issue.

Engine Temperature Results

To confirm that we were achieving the temperature differential necessary in order to run the Stirling engine, we used thermocouples to record the internal temperatures. By using a National Instruments Data Acquisition Box and a LabVIEW program, seen in Appendix C, we were able to record temperature data during testing. The results in Figure 33 show the increase oftemperature as heat was applied over time. The highest temperature achieved inside the hot piston was 423.8°C while the temperature inside the cooler piston was at 29.3°C, giving a temperature difference between the two pistons of 394.5°C. The fluctuations in the temperaturearound the 350 second mark are the result of readjusting the propane burner.



IV. CONCLUSIONS

Throughout the process of designing, manufacturing, and testing our Stirling engine, we have uncovered many new insights, problems and solutions concerning the different portions of the engine. We applied our knowledge of thermodynamics to the design of the engine, and developed formulas to predict its power output at different temperature differentials. Overcomingmany engineering and design challenges, we were able to build the engine and include the tools necessary to record data inside the engine. From the numerical analysis, we found that our engine is achieving a power output of only 65.2 Watts. This was not large enough to keep the engine in motion after applying an initialpull start. Changes necessary to increase the work output of the engine would include pressurizing the system, as the value for the pressure inside the system has a linear correlation tothe work output. Increasing the pressure inside the system would allow the gasses inside to exhibit incompressible flow, and improve mass transfer between the hot and cold sides of the engine. If the machine is pressurized however, there is a risk of explosive decompression, and a pressure gauge becomes necessary to monitor the system. Another route to pursue in order to improve the engine is to reduce the dead volume. The calculated dead volume inside the system of 176.32 cm^3 can be decreased by changing the size and shapes of the pipes, heater and cooler. The shape of the heater currently works but is not ideal for the flow of the gasses from inside the hot piston to the piping connecting to the cool side of the engine.

Due to the restraints on our resources and prioritizing the design and manufacturing of the necessary cooler and heater sections, the process of developing the compressor to an optimum state was rather neglected. The compressor could be improved by replacing or rebuilding portions of the engine to better suit the needs of a Stirling engine.

V. FUTURE SCOPE

Several problems remain to be addressed within the engine. First among them is theoverall lack of useful work output by the engine. Most of the work is being absorbed by thefriction of the crankshaft and piston linkages, and possibly by inferior bearings. Further inspection of the compressor block is recommended to isolate and rectify these problems.

As mentioned in the methodology, a serious risk of engine damage was mitigated by abandoning the mesh type regenerator in favor of a foil-type. However, it is the opinion of the team that a mesh regenerator without the frangibility of steel wool would be more efficient, and have less dead volume, than our current system. Dead volume can also be reduced by decreasingthe diameter of the connecting pipe between the caps. Given the relatively low swept volume of the pistons, it is likely that this excess pipe volume is significantly reducing the mass transfer rate of hot and cold working fluid.

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