Solar Powered Sterling Engine

Summer Project - 2013

Group 5

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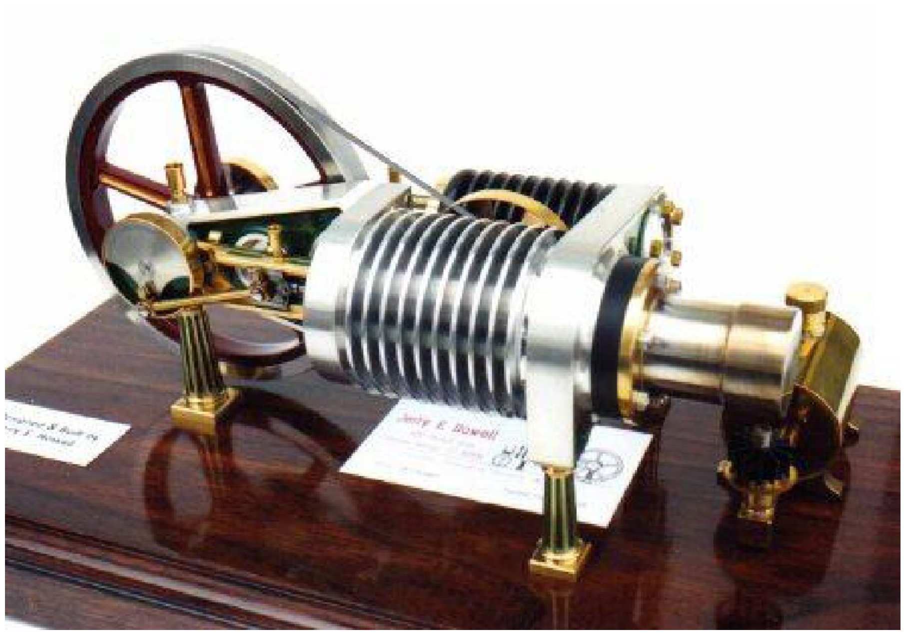

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- *www.gobookee.net*

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Kashish Goyal

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Team Leader

Project Summary

Solar energy is one of the more attractive renewable energy sources that can be used as an input energy source for heat engines. In fact, any heat energy source can be used with the Sterling engine. The solar radiation can be focused onto the displacer hot-end of the Sterling engine, thereby creating a solar-powered prime mover. The direct conversion of solar power into mechanical power reduces both the cost and complexity of the prime mover. In theory, the principal advantages of Sterling engines are their use of an external heat source and their high efficiency. Sterling engines are able to use solar energy that is a cheap source of energy. Since during two-thirds of the day, solar energy is not available, solar/fuel hybrids are needed.

The Sterling engine is an efficient engine that requires outside heat to operate. Since the combustion of the Sterling engine is continuous process, it can burn fuel more completely and is able to use all kinds of fuel with any quality. Because of its simple construction, and its manufacture being the same as the reciprocating internal combustion engine, and when produced in a large number of units per year, the Sterling engine would obtain the economy of scale and could be built as a cheap power source for developing countries.

Due to the above mentioned extra-ordinary advantages and immense scope of further research and improvement our group decided to make an attempt at building the prototype of a Gamma type Sterling Engine.

There were several factors that influenced our decision. The Gamma type is very similar to the Beta type, except that the power piston is mounted beside the displacer piston. This allows for much easier construction. Also, a Gamma type engine requires a much smaller heat differential to operate when compared to the alpha and beta engines.

The gamma-configuration uses separated cylinders for the displacer and the power pistons, with the power cylinder connected to the displacer cylinder. The displacer moves working fluid between the hot space and the cold space of the displacer cylinder through the heater, regenerator, and cooler. In this configuration, the power piston both compresses and expands the working fluid. The gamma-configuration with double-acting piston arrangement has theoretically the highest possible mechanical efficiency. This configuration also shows good self-pressurization.

With the advancing of time the scope of improvement and increase in the fields of application of sterling engines, this particular area of thermal engines posses immense potential for budding engineers as well as designers.

With this project of ours, we wish to accomplish the task of enlightening the world towards the aggravated potential and vital scopes of application of this simple machine having the capability to revolutionize the field of mechanical power generation and application.

Objectives and Specifications

With this project namely “Solar Powered Sterling Engine”, we wish to accomplish the following objectives: (in sequence)

- Utilization of the most abundant energy resource available on the planet which also happens to be renewable i.e. Solar Energy.
- Generation of power using completely non-pollutant methods.
- Constructing an engine ideal for any heat source i.e. high compatibility.
- Generate power using the available energy resource which is greater than generated by any other kind of device using same resource.
- Designing a compact engine requiring minimal of space.

The project includes the study on following components:

- Scope of eco-friendliness of the device.
- Efficiency of the device.
- Construction and working of a prototype of the device.
- Maximum power output of the device within feasible working temperatures.
- Application of the device in various fields.
- Cost analysis including the manufacturing, procuring and maintenance cost of the device’s components.

The Sterling engine prototype has the following specifications of construction:

- A 20cm dia. Flywheel
- A 50mm dia. Piston
- Connecting Rod
- A 40mm dia. Displacer (Aluminum)
- Steel pipe 225mm length
- Cylinder Body with integrated fins
- Shaft (step turned at dia. 21, 20mm)
- Wooden base (250x650mm)
- Link (for connection with the flywheel)
- Connecting pipe (for fluid transfer)
- Bearings
- Plummer Blocks (for bearing supports)
- Washers (for pin type joints)

INTRODUCTION

Solar energy is one of the more attractive renewable energy sources that can be used as an input energy source for heat engines. In fact, any heat energy source can Be used with the Sterling engine. The solar radiation can be focused onto the displacer hot-end of the Sterling engine, thereby creating a solar-powered prime mover.

The direct conversion of solar power into mechanical power reduces both the cost and complexity of the prime mover. In theory, the principal advantages of Sterling engines are their use of an external heat source and their high efficiency. Sterling engines are able to use solar energy that is a cheap source of energy. Since during two-thirds of the day, solar energy is not available, solar/fuel hybrids are needed. Since the combustion of the Sterling engine is continuous process, it can burn fuel more completely and is able to use all kinds of fuel with any quality. Because of its simple construction, and its manufacture being the same as the reciprocating internal combustion engine, and when produced in a large number of units per year, the Sterling engine would obtain the economy of scale and could be built as a cheap power source for developing countries.

For solar electric generation in the range of 1–100 kWe, the Sterling engine was considered to be the cheapest. Although the Sterling engine efficiency may be low, reliability is high and costs are low. Moreover, simplicity and reliability are keys to a cost effective Sterling solar generator.

Sterling engines are mechanical devices working theoretically on the Sterling cycle, or its modifications, in which compressible fluids, such as air, hydrogen, helium, nitrogen or even vapors, are used as working fluids. The Sterling engine offers possibility for having high efficiency engine with less exhaust emissions in comparison with the internal combustion engine. The earlier Sterling engines were huge and inefficient. However, over a period of time, a number of new Sterling engine models have been developed to improve the deficiencies.

The modern Sterling engine is more efficient than the early engines and can use any high temperature heat source. The Sterling engine is an external combustion engine. Therefore, most sources of heat can power it, including combustion of any combustible material, field waste, rice husk or the like, biomass methane and solar energy. In principle, the Sterling engine is simple in design and construction, and can be operated easily.

Direct solar-powered Sterling engines may be of great interest to countries where solar energy is available in unlimited quantity. To use direct solar energy, a solar concentrator and absorber must be integrated with the engine system.

The Sterling engine could be used in many applications and is suitable where:

- Multi-fueled characteristic is required.
- A very good cooling source is available.
- Quiet operation is required.
- Relatively low speed operation is permitted.
- Constant power output operation is permitted.
- Slow changing of engine power output is permitted.

- A long warm-up period is permitted.

Sterling engine configurations

Mechanical configurations of the Sterling engine

Various machine components have been combined to provide the Sterling cycle. The cycle provides a constant-volume process during the transfer of working fluid between the hot and cold space of the engine, and provides a constant-temperature heating and cooling process during compression and expansion. The compression and expansion processes of the cycle generally take place in a cylinder (called power cylinder) with a piston (called power piston). A displacer piston (simply called displacer) shuttles the working fluid back and forth through the heater, regenerator, and cooler at constant volume. A displacer that moves to the cold space displaces the working fluid from the cold space causing it to flow to the hot space and vice versa. Three different configurations, namely the alpha-, beta-, and gamma-configurations, are commonly used. Each configuration has the same thermodynamic cycle but has different mechanical design characteristics. In the alpha-configuration a displacer is not used. Two pistons, called the hot and cold pistons, are used on either side of the heater, regenerator,

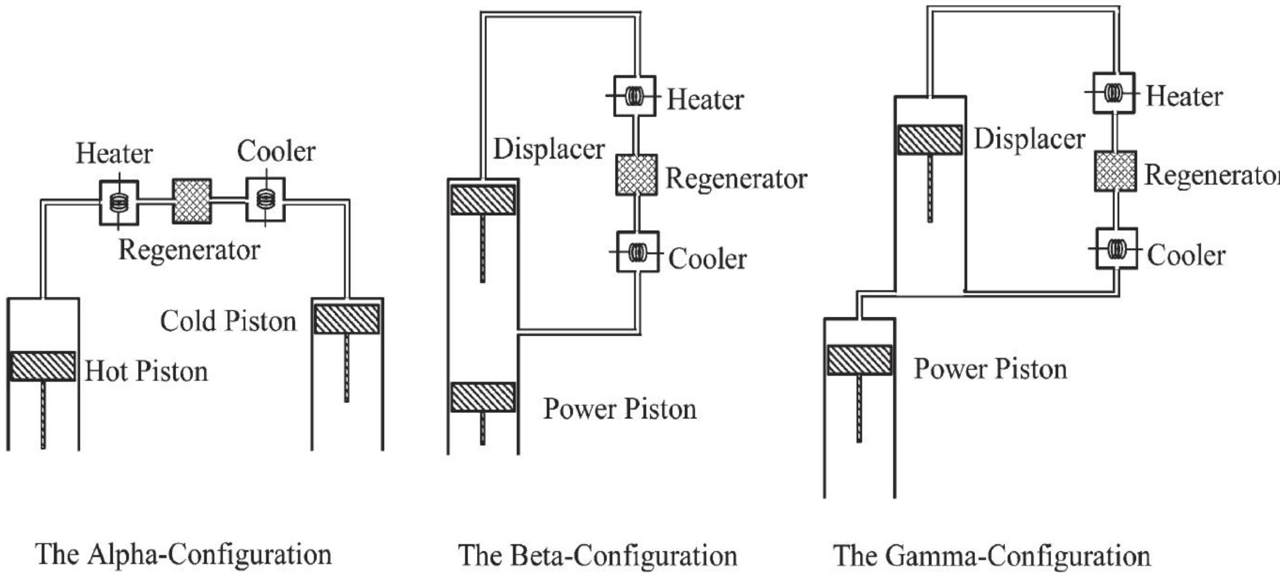


Fig. 1. Three basic mechanical configurations for Stirling engine.

and cooler. These pistons move uniformly in the same direction to provide constant-volume heating or cooling processes of the working fluid. When all the working fluid has been transferred into one cylinder, one piston will be fixed and the other piston moves to expand or compress the working fluid. The expansion work is done by the hot piston while the compression work is done by the cold piston.

In the beta-configuration, a displacer and a power piston are incorporated in the same cylinder. The displacer moves working fluid between the hot space and the cold space of the cylinder through the heater, regenerator, and cooler. The power piston, located at the cold space of the cylinder, compresses the working fluid when the working fluid is in the cold space and expands the working fluid when the working fluid is moved into the hot space.

The gamma-configuration uses separated cylinders for the displacer and the power pistons, with the power cylinder connected to the displacer cylinder. The displacer moves working fluid between the hot space and the cold space of the displacer cylinder through the heater, regenerator, and cooler. In this configuration, the power piston both compresses and expands the working fluid. The gamma-configuration with double-acting piston arrangement has theoretically the highest possible mechanical efficiency. This configuration also shows good self-pressurization. However, the engine cylinder should be designed in vertical type rather than horizontal in order to reduce bushing friction.

Low Temperature Differential engine configurations (LTD)

A low temperature differential (LTD) Sterling engine can be run with small temperature difference between the hot and cold ends of the displacer cylinder. It is different from other types of Sterling-cycle engines, which have a greater temperature difference between the two ends, and therefore the power developed from the engine can be greater.

LTD engines may be of two designs. The first uses single-crank operation where only the power piston is connected to the flywheel, called the Ringbom engine. This type of engine, that has been appearing more frequently, is based on the Ringbom principle. A short, large-diameter displacer rod in a precise-machined fitted guide has been used to replace the displacer connecting rod. The other design is called a kinematic engine, where both the displacer and the power piston are connected to the flywheel. The kinematic engine with a normal 90^{o} phase angle is a gamma configuration engine.

Some characteristics of the LTD Sterling engine are as follows:

- Displacer to power piston swept volumes ratio is large;
- Diameter of displacer cylinder and displacer is large;
- Displacer is short;
- Effective heat transfer surfaces on both end plates of the displacer cylinder are large;
- Displacer stroke is small;

- Dwell period at the end of the displacer stroke is rather longer than the normal Sterling engine;
- Operating speed is low.

LTD Sterling engines provide value as demonstration units, but they immediately become of interest when considering the possibility of power generation from many low temperature waste heat sources in which the temperature is less than 100^{o}C. A calculation using the Carnot cycle formula shows that an engine operating with a source temperature of 100^{o}C and a sink temperature of 35^{o}C gives a maximum thermal efficiency of about 17.42%. If an engine could be built for achieving 50% of the maximum thermal efficiency, it would have about 8.71% overall Carnot efficiency. Even the calculated thermal efficiency seems rather low, but LTD Sterling engines could be used with free or cheap low temperature sources. This engine should be selected when the low cost engines are put into consideration.

Although the specific power developed by LTD Sterling engines is low, lightweight and cheap materials such as plastics can be used as engine parts.

Principle of operation

The Sterling hot air engine is a simple type of engine that uses a compressible fluid as the working fluid. Because the working fluid is in a closed system, there are no problems with contamination and working fluid costs. Heat transfer to the working fluid is very important. High mass flow is needed for good heat transfer.

The working fluid should be that of low viscosity to reduce pumping losses. Using higher pressure or lower viscosity, or combinations thereof, could reduce the high mass flow required.

The Sterling engine could theoretically be a very efficient engine in upgrading from heat to mechanical work with the Carnot efficiency. The thermal limit of the operation of the Sterling engine depends on the material used for construction. Engine efficiency ranges from about 30 to 40% resulting from a typical temperature range of 923–1073 K, and a normal operating speed range from 2000 to 4000 rpm.

Sterling cycle

The ideal Sterling cycle has three theoretical advantages. First, the thermal efficiency of the cycle with ideal regeneration is equal to the Carnot cycle. During the transfer strokes, the regenerator, which is typical temporary energy storage, rapidly absorbs and releases heat to the working fluid which is passing through.

Therefore, the quantity of heat taken from the external heat source is reduced; this results in improving the thermal efficiency.

The second advantage, over the Carnot cycle, is obtained by substitution of two isentropic processes with two constant-volume processes. This results in increasing the *p*–*v* diagram area. Therefore, a reasonable amount of work from the Sterling cycle is obtained without the necessity to use very high pressures and large swept volumes, as in the Carnot cycle. The Sterling cycle compared with the Carnot cycle between the same given limits of pressure, volume, and temperature, is shown in. The shaded areas 2C-2-3 and 1-4C-4 indicate the additional work available by replacing two isentropic processes with two constant-volume processes. The Carnot cycle isothermal processes (1-2C and 3-4C) are respectively extended to process 1–2 and 3–4. The amount of available work is increased in the same proportion as the heat supplied to—and rejected from—the Sterling cycle.

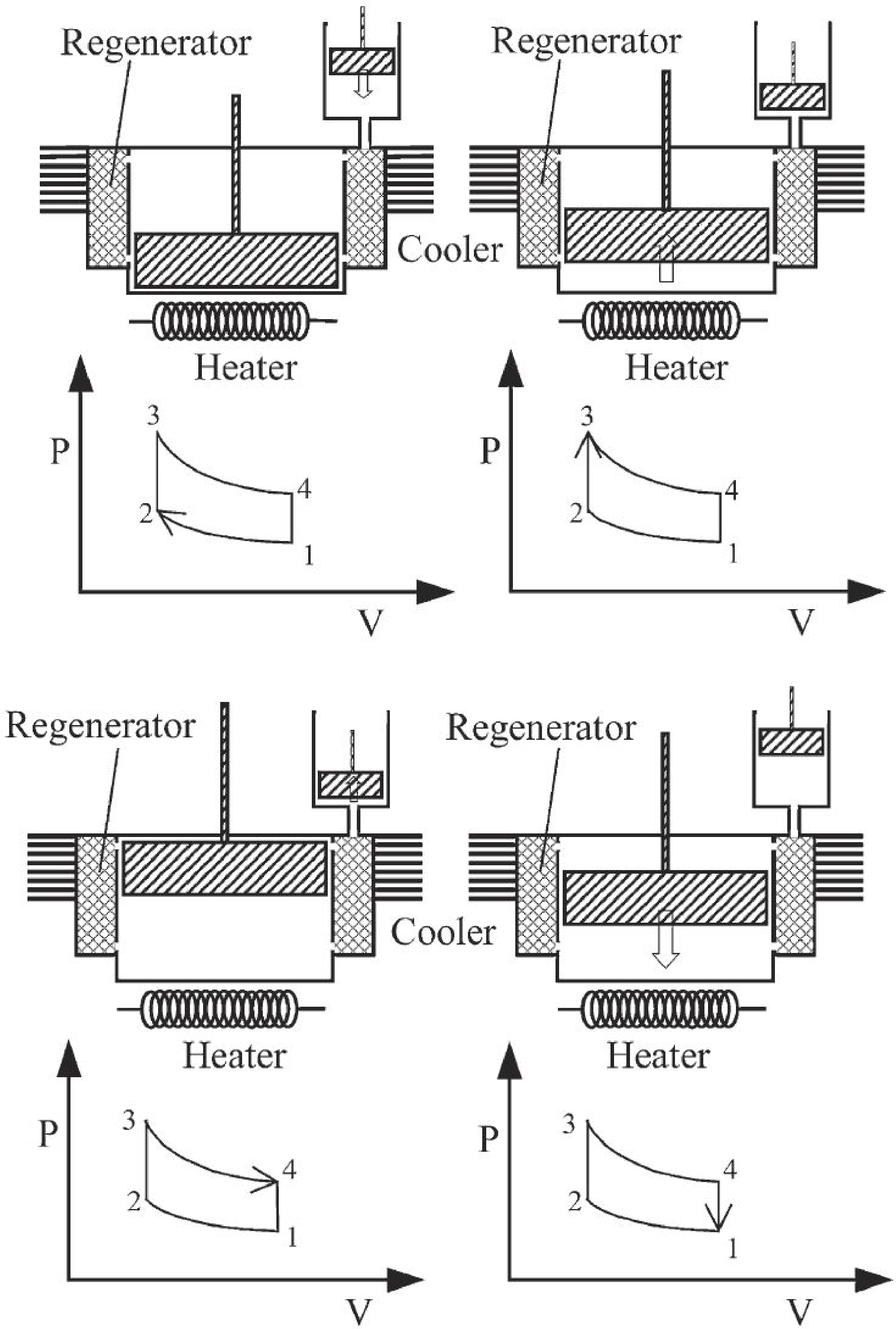
The third advantage has recently been discovered. Compared with all reciprocal piston heat engines working at the same temperature limits, the same volume ratios, the same mass of ideal working fluid, the same external pressure, and mechanism of the same overall effectiveness, the ideal Sterling engine has the maximum possible mechanical efficiency. These three advantages reveal that the Sterling engine is a theoretical equivalent of all heat engines.

Sterling engine operation

Isothermal compression process 1–2 (heat transfer from working fluid at low temperature to an external sink): After the displacer has pushed the working fluid into the cold space of the cylinder, where it was cooled, it was then held stationary at its top dead center (TDC). This indicated the state 1 and the pressure at this state is $p1$. The power piston is then being pushed from bottom dead center (BDC) to TDC by flywheel momentum helped by partial vacuum created by the cooling working fluid. The working fluid is in the cold space and is under compression by power piston, which is approaching TDC, and compressing working fluid from 1 to 2 at constant temperature. The work done on the working fluid is indicated by the area under process 1–2.

Constant-volume heating process 2–3 (heat transfer to the working fluid from regenerator): The displacer is moving from TDC to BDC and transferring working fluid from the cold space to the hot space, while the power piston remains stationary at its TDC, awaiting increase in pressure as a result of expanding working fluid. The displacer is pushing the working fluid into the hot space, passing through a regenerator which has stored heat, and already a certain amount is being heated. Heat given up by the regenerator raises the temperature and pressure of the working fluid from 2 to 3 at constant volume. Heat stored in the regenerator is added to the working fluid.

Isothermal expansion process 3–4 (heat transfer to the working fluid at high temperature supplied by an external source): After the displacer has pushed all the working fluid into the hot space, with a corresponding increase in pressure to the maximum, it is then kept at rest at its BDC. The working fluid is in the hot space and is expanding to pressure $p4$, while a constant temperature process 3–4 is maintained applied at the hot space. The power piston is being pushed from TDC to BDC by the increased pressure, and is applying force to the flywheel, thus creating mechanical energy. This energy will be utilized throughout the remaining processes of the cycle. The work done by the working fluid is indicated by the area under process 3–4.


Regenerator
Cooler
Heater
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1
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Regenerator
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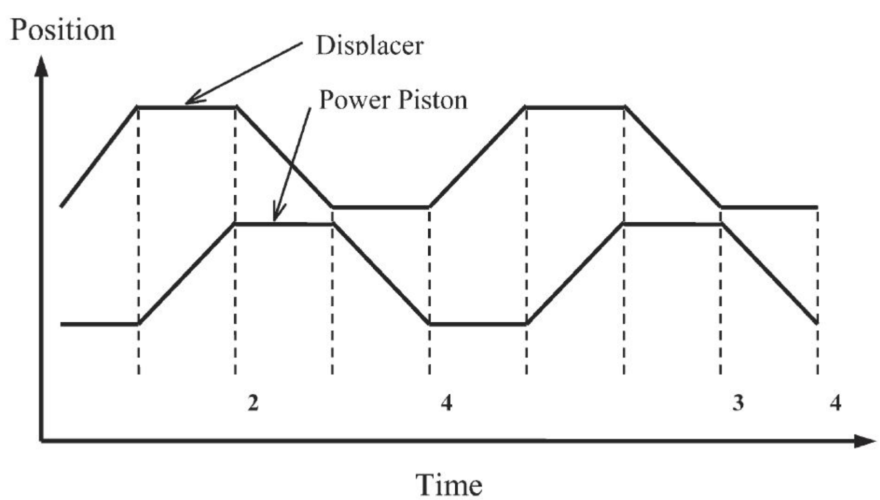
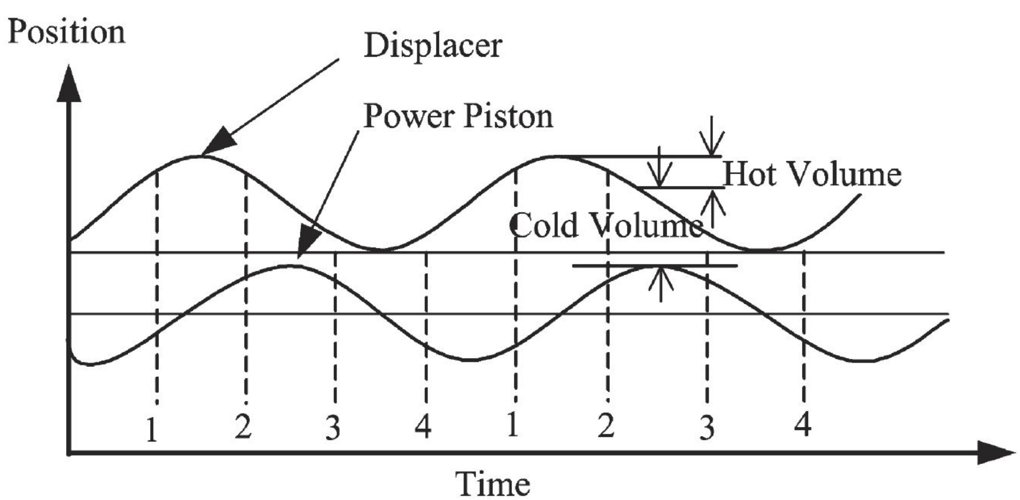
Constant-volume cooling process 4–1 (heat transfer from the working fluid to the regenerator): After the power piston has reached its BDC and has supplied its energy to the flywheel, it remains stationary and is ready to travel back to TDC under flywheel momentum and the sucking action of the partial vacuum created by the falling pressure. The displacer is moving from BDC to TDC and is transferring working fluid to the cold space where the pressure will fall and a partial vacuum is created, through the regenerator, causing a fall in temperature and pressure of the working fluid from 4 to 1 at constant volume. Heat is transferred from the working fluid to the regenerator.

Motion diagram



The movement of the power piston and the displacer require an out-of-phase motion. There is a calculated gap both in time and in motion then the displacer and the power piston do not move backwards and forwards at the same time. To obtain this out-of-phase motion, this gap should be a 90^o phase angle, with the stroke of the displacer always leading the power piston by approximately 90^o. The function of the displacer is to transfer working fluid from one end of the cylinder to the other. The function of the power piston is to convert the expansion of working fluid at high pressure and compression of working fluid at low temperature and to transfer this conversion into motion by means of a crankshaft and flywheel. Figure shows the ideal motions of a gamma-configuration Sterling engine and figure shows how well sinusoidal motion can fit the ideal motion.

Sterling cycle efficiency



For an air-standard Sterling cycle, the amounts of heat added and rejected per unit mass of working fluid are as follows:

$Q_{added} = xc_v(T_H\_T_C)\ \_\ RT_H \ln v_1 / v_2$ (1)

$Q_{rejected} = xc_v(T_C\_T_H)\ \_\ RT_C \ln v_2 / v_1$ (2)

Where x is the fractional deviation from ideal regeneration (i.e. $x = 1$ for no regeneration and $x = 0$ for ideal regeneration), C_v the specific heat capacity at constant volume in J/(kg K), T_H the source temperature in the Sterling cycle in K, T_C the sink temperature in K, R the gas constant in J/(kg K), v_1 and v_2 are specific volumes of the constant-volume regeneration processes of the cycle in m3/kg, and

v_2/v_1 is the volume compression ratio. The Sterling cycle efficiency can be expressed as:

$$\eta_s = \frac{1-\frac{T_C}{T_H}}{1-(xcv\ /R\ ln\ v1\ /\ v2)(1-TC/TH)}$$

Engine indicated work

Schmidt formula

Schmidt showed a mathematically exact expression for determining the indicated work per cycle of a Sterling engine. The Schmidt formula may be shown in various forms depending on the notations used. Because of its complexity, it takes time to verify the calculation.

Engine power output

Beale formula

Beale noted that the power output of several Sterling engines observed could be calculated approximately from the equation:

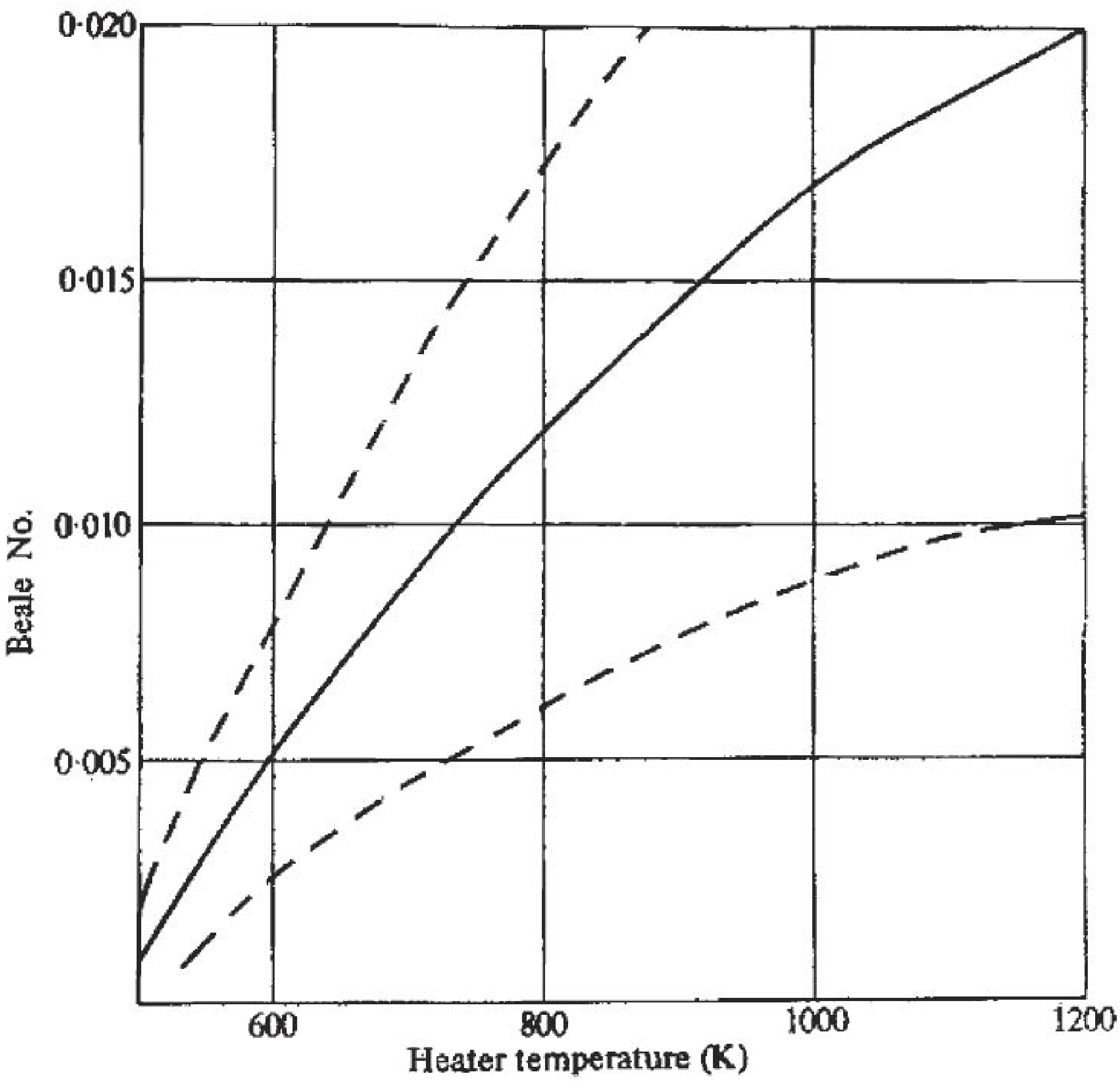
$P = 0.015\ p\text{m}\ fV\text{P}$ (1)

Where P is the engine power output in Watts, pm the mean cycle pressure in bar, f the cycle frequency in Hz, and VP is displacement of power piston in cm3. The Beale formula can be used for all configurations and for various sizes of Sterling engines.

Eq. 1 may be written in a general form as follows:

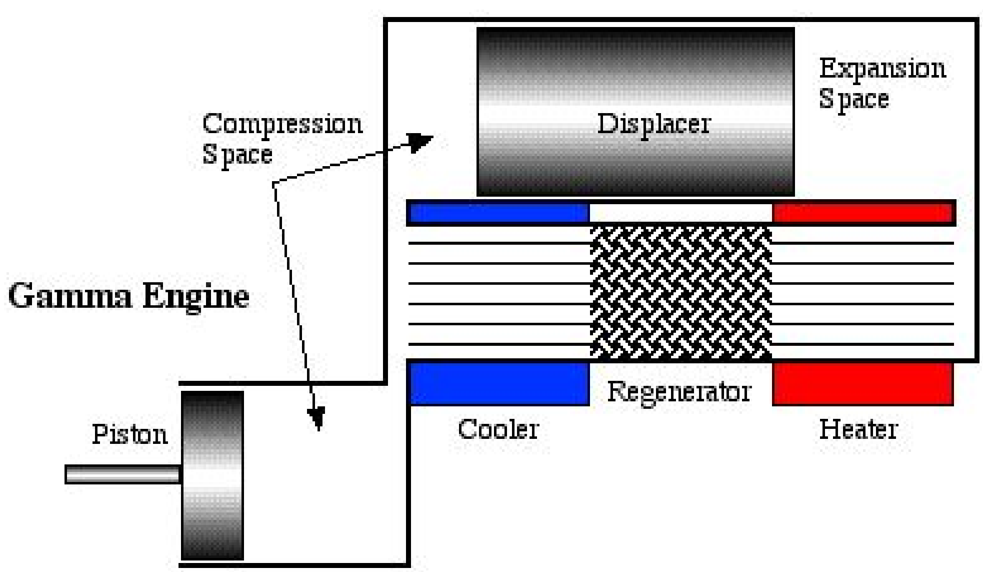
$P/\ (p\text{m}f\ V\text{P}) = \text{constant}$ (2)

The resulting dimensionless parameter $P/\ (p\text{m}fV\text{P})$ is called the Beale number. It is clear that the Beale number is a function of both the source and sinks temperatures. The solid line in figure indicates the relationship between the Beale number and source temperature. The upper bound represents the high efficiency, well-designed engines with low sink temperatures, while the lower bound represents the moderate efficiency, less well-designed engines with high sink temperatures.



GAMMA TYPE STERLING ENGINE

A gamma Sterling engine is simply a beta Sterling engine in which the power piston mounted in a separate cylinder alongside the displacer piston cylinder, but is still connected to the same flywheel. The gas in the two cylinders can flow freely between them and remains a single body. This configuration produces a lower compression ratio but is mechanically simpler and often used in multi cylinder Sterling engines. Gamma type engines (figure no.3) have a displacer and power piston, similar to Beta machines, but in different cylinders. This allows a convenient complete separation between exchangers associated with the displacer cylinder and the compression and expansion work space associated with the piston. Furthermore during the expansion process some of the expansion must take place in the compression space leading to a reduction of specific power.



BACKGROUND

First era of Sterling engines

The Sterling engine was the first invented regenerative cycle heat engine. Robert Sterling patented the Sterling engine in 1816 (patent no. 4081). Engines based upon his invention were built in many forms and sizes until the turn of the century.
Because Sterling engines were simple and safe to operate, ran almost silently on any combustible fuel, and were clean and efficient compared to steam engines, they were quite popular. These Sterling engines were small and the power produced from the engine was low (100 W to 4 kW). In 1853, John Ericsson built a large marine Sterling engine having four 4.2 m diameter pistons with a stroke of 1.5 m producing a brake power of 220 kW at 9 rpm. The first era of the Sterling engine was terminated by the rapid development of the internal combustion engine and electric motor.

Second era of Sterling engines

The second era of the Sterling engine began around 1937 , when the Sterling engine was brought to a high state of technological development by the Philips Research Laboratory in Eindhoven, Holland, and has progressed continuously since that time. Initial work was focused on the development of small thermal-power electric generators for radios and similar equipment used in remote areas.
New materials were one of the keys to Sterling engine success. The Philips research team used new materials, such as stainless steel.

Another key to success was a better knowledge of thermal and fluid physics than in the first era. The specific power of the small '102C' engine of 1952 was 30 times that of the old Sterling engines. The progress in further development made by Philips and many other industrial laboratories, together with the need for more energy resources, has sustained the second era of Sterling engine development until today.

Solar-powered Sterling engines in the first era

In 1864, Ericsson invented a solar-powered hot air engine using a reflector to heat the displacer cylinder hot-end. Jordan and Ibele reported that between 1864 and 1870, Ericsson used parabolic trough collectors to heat steam and used steam to drive his engine. In 1870, the Sterling engine was adapted by Ericsson to operate with solar energy. Spencer reported that in 1872, Ericsson built an open-cycle hot-air engine using a spherical mirror concentrator. This engine was the first solar-powered hot air engine. It was also reported that the engine could work at 420 rpm at noon on a clear sky day in New York. Meinel and Meinel commented on the conclusions made by Ericsson pointing out that solar-powered engines would be economical only in remote areas where sunshine was available and pointing out their cost was 10 times higher than conventional engines. The amount of solar-powered Sterling engines built in the first era was quiet small. Reader and Hooper reported that in 1908 a solar-powered Sterling engine was proposed for a water pumping system.

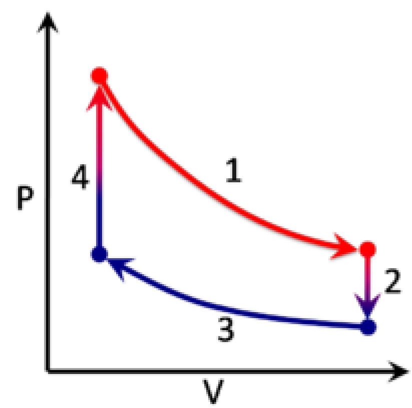
Solar-powered Sterling engines in the second era

During 1950–1955, Ghai and Khanna worked with an open cycle solar-powered Sterling engine using a parabolic collector in India. The solar energy was focused on the metal engine head but they had problems with heat loss. Jordan and Ibele described the 100 W solar-powered Sterling engines for water pumping. Ghai pointed out the point of economy and technical simplicity of a solar powered device even though its competitor was the internal combustion engine. Later works related to solar-powered Sterling engines and heat pipes were previously reviewed by Spencer. Other works concerning the different varieties and arrangements of the cylinder and displacer including construction and operation of solar-powered Sterling engines have been reported by Daniels.

Other forms of solar powered Sterling Engines:

- *Sterling engines with transparent quartz window*
- *Sterling engines with concentrating collector*
- *Solar dish/engine technology*

Basic Theory



The idealized Sterling cycle consists of four thermodynamic processes acting on the working fluid:

- Isothermal Expansion.

  The expansion-space and associated heat exchanger are maintained at a constant high temperature, and the gas undergoes near-isothermal expansion absorbing heat from the hot source.

- Constant-Volume (known as iso-volumetric or isochoric) heat-removal.

  The gas is passed through the regenerator, where it cools, transferring heat to the regenerator for use in the next cycle.

- Isothermal Compression.

  The compression space and associated heat exchanger are maintained at a constant low temperature so the gas undergoes near-isothermal compression rejecting heat to the cold sink

- Constant-Volume (known as iso-volumetric or isochoric) heat-addition.

  The gas passes back through the regenerator where it recovers much of the heat transferred in 2, heating up on its way to the expansion space.

Theoretical thermal efficiency equals that of the hypothetical Carnot cycle - i.e. the highest efficiency attainable by any heat engine. However, though it is useful for illustrating general principles, the text book cycle is a long way from representing what is actually going on inside a practical Sterling engine and should only be regarded as a starting point for analysis. In fact it has been argued that its indiscriminate use in many standard books on engineering thermodynamics has done a disservice to the study of Sterling engines in general.

Other real-world issues reduce the efficiency of actual engines, due to limits of convective heat transfer, and viscous flow (friction). There are also practical mechanical considerations, for instance a simple kinematic linkage may be favored over a more complex mechanism needed to replicate the idealized cycle, and limitations imposed by available materials such as non-ideal properties of the working gas, thermal conductivity, tensile strength, creep, rupture strength, and melting point.

A question that often arises is whether the ideal cycle with isothermal expansion and compression is in fact the correct ideal cycle to apply to the Sterling engine. Professor C. J. Rallis has pointed out that it is very difficult to imagine any condition where the expansion and compression spaces may approach isothermal behavior and it is far more realistic to imagine these spaces as adiabatic. An ideal analysis where the expansion and compression spaces are taken to be adiabatic with isothermal heat exchangers and perfect regeneration was analyzed by Rallis and presented as a better ideal yardstick for Sterling machinery. He called this cycle the 'pseudo-Sterling cycle' or 'ideal adiabatic Sterling cycle'. An important consequence of this ideal cycle is that it does not predict Carnot efficiency. A further conclusion of this ideal cycle is that maximum efficiencies are found at lower compression ratios, a characteristic observed in real machines.

PRACTICE IN INDUSTRY

Intensive research by Philips and industrial laboratories led to the development of small Sterling engines with high efficiencies of 30% or more. In 1954, Philips developed an engine using hydrogen as a working fluid. This engine produced 30 kW for a maximum cycle temperature of 977 K at 36% thermal efficiency. The efficiency of the same engine was later improved to 38%. The experimental studies of engines of various sizes up to 336 kW were studied.

Other attempts to further develop Sterling engines under license of Philips were carried out by General Motors from 1958 to 1970. Other licenses were granted by Philips to United Sterling AB of Malmo, Sweden in 1968 and to the West German consortium of MAN and MWM in 1967. In 1973, the Philips/Ford 4-125 experimental automotive Sterling engine accomplished a specific power of over 300 times that of the early Sterling engines.

Sterling engines for rural and remote areas

Trayser and Eibling carried out a design study to determine the technical feasibility of developing a 50 W portable solar-powered generator for use in remote areas. The results of their study indicate that it is possible to build a solar-powered lightweight portable, reliable, Sterling engine at a reasonable cost.

Some satellites get energy through a Sterling engine. The efficiency is particularly high considering the great differences in temperature. The hot source consists of radioactive isotopes. The use of radioactive elements is not very ecological; it presents risks at the time of the take-off of the rocket. The justification comes owing to the fact that solar panels can be dirtied or be destroyed in certain zones of space, as near Mars.

When one takes advantage of energy from the Sun, one uses a reflective dish which concentrates the sunbeams in only one point: the focus of the dish where you install the Sterling engine.
In the United States, great reflective dishes were installed in the desert with Sterling engines to generate electricity without buying fuel!
(NB: photovoltaic panels have a poor performance, about 15%. Therefore, at equal power, their surface is larger than reflectors of a Sterling engine).

The reversibility of the Sterling engine is used in order to produce cold in an industrial way. Its efficiency is then excellent. In this type of operation, we provide mechanical energy to the engine. In fact, we transfer calories from the cold source the hot source, like in a domestic refrigerator. This mode of operation is so efficient that we use this type of installation to liquefy certain gas.
Paradox: use sun for generating electricity by a Sterling engine, then this electricity drives a Sterling engine for making cold.

Cryogenics is the science of things that are exceedingly cold and Sterling engines are one tool that can be used to make things exceedingly cold. It's not obvious but a Sterling engine is a reversible device. If you heat one end and cool the other, you get mechanical work out, but if you put mechanical work in, by connecting an electric motor, one end will get hot and the other end will get cold. If you design the machine correctly, the cold end will get extremely cold. In fact, Sterling coolers have been made that will cool below 10 degrees Kelvin.
Micro Sterling coolers have been produced in large numbers for cooling infrared chips down to 80 degrees Kelvin for use in night vision devices.

WORK DISTRIBUTION

The complete project namely “Solar Powered Sterling Engine” can be divided into the following categories:

- Design

  Design part of the project involves the internet research, CAD modeling, listing of the materials required, assembly design of components, dimension analysis and feasibility study of the project.

  The design team included Kashish Goyal and Gaurav Chand . CAD models were prepared by Kashish Goyal. Assembly feasibility study was carried out by Gaurav.
- Material Procurement

  This involves the comprehensive market study and research for availability of materials of various sizes, dimensions, standards and specifications.

This team headed by Paramvir Singh included Puneet Goyal and Naveen Sharma. Naveen Sharma handled the finances.

- Fabrication
  Fabrication involves the manufacturing processes to be used to fabricate the components and form an assembly.
  Fabrication was efficiently carried out by Sahil Goyal, Puneet Goyal, Inderpal Singh, Avish Gambhir, Jatinder Kumar.
- Report Generation
  Report is the most important part which is an entire overview of the project. It gives the basic idea of the concept, application and scope of the project. Report design involved efforts of Kashish Goyal and Inderpal singh.
- Presentation
  It is the mode of communication between the project pursuers and the party interested for some purpose in the project.
  Presentation was prepared by Kashish Goyal.

Component Details

Sr. No.	Name of Component	Manufactured	Purchased
1.	Shaft	**	
2.	Displacer Cylinder	**	
3.	Bearings		**
4.	Piston		**
5.	Cylinder Body		**
6.	Spherical Dish		**
7.	Displacer	**	
8.	Connecting Rod		**
9.	Flywheel	**	
10.	Links	**	
11.	Base	**	
12.	Connecting Pipe		**
13.	Nuts & Washers		**
14.	Piston Crank	**	
15.	Mirror Cutouts	**	

Name Of Component	Manufacturing Processes Used	Machine Used
Shaft	Step Turning, Grooving, Facing	Lathe Machine
Displacer	Casting, Turning, Facing, Welding	Foundry Shop, Lathe & Welding
Base	Carpentry, Sheet Metal	Carpentry Shop
Links	Welding, Cutting, Grinding	Welding, Hack Saw, Grinder
Displacer Cylinder	Grinding, Cutting, Welding	Grinder, Hack Saw, Welding
Piston Crank	Cutting, Welding	Spot Welder, Press shear
Mirror Cutouts	Cutting, Pasting	Diamond tip Cutter

COST ANALYSIS

S.N0.	COMPONENT	COST(in rupees)
1	Dish	

CONCLUSION

Given our project objectives we feel that the opportunity to work on this endeavor enhanced our appreciation and awareness of the resources and technologies that we take for granted daily. The design and materials used to construct the system were kept to a mechanical simplistic model to allow for better integration in developing societies. Although certain aspects of the system proved to be difficult problems the attempts to overcome them brought many success and setbacks. Our interest and analysis of solar powered Sterling engine may inspire future work on the system which would advance our last objective, which was to raise greater awareness of solar powered engines as a low cost energy source for applications found in developing societies.

Today, there are many companies developing Sterling devices for niche markets, such as cogeneration units and power generation using alternative fuels. Sterling engines have come a long way from the large and heavy engines of the 19th century, thanks to advancements in materials, manufacturing processes, theory and analysis methods.

We have learned a great deal on the operation of the Sterling engine especially gamma type sterling engine.

SCOPE OF FURTHER IMPROVEMENT

Sterling engine posses a vast scope of improvement. Today it occupies one of the largest proportions of research budgets. This engine has the highest level of portability, compatibility, and durability than any other engines. The various fields where we can hope to find the sterling engine working in the near future is listed as under:

- Modification to incorporate another natural heat resource i.e. Geothermal energy.
- Compactness of Design towards micro engine.
- Automobile Exhaust applications to improve overall vehicular efficiency.
- Reduction in the internal losses of the assembly.
- Substitute for refrigerants and thus more Eco –friendly.
- And many more...

REFERENCES

www.wikipedia.com

http://www.robertSterlingengine.com

http://www.technicaljournalsonline.com

http://www.gobookee.net