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Research Paper

MODIFICATION OF AN ALPHA STIRLING ENGINE WITH AN VENTURI BASED WORKING FLUID CONTROL SYSTEM TO PROMOTE ITS AUTOMOTIVE APPLICATIONS

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An alpha type stirling engine of two pistons, two cylinders type is theoretically explained. A graphical model of the engine is developed and then the various cycles of this engine are briefly elaborated. The efficiency is proved to be maximum (50% of its theoretical efficiency unlike other engines). Limitations which doesn't permit this engine to be used commercially in automotive applications are briefly analyzed and a study to overcome this limitations are made. A transient variation in engine working is explained by the alterations in engine's components and via the coupling of an venturi based working fluid control system. An extensive parametric study of effects of different operating and geometric parameters has been performed and proved that the engine can be used successfully for commercial applications. Study of an solar powered stirling engine powered through parabolic collectors was explained and various possible industrial heat sources were listed from which the heat can be utilized to run the engine.

Keywords: Solar stirling engine, Venturi, Working fluid control system, Automotive applications

INTRODUCTION

A Stirling "Air" Engine is a mechanical device which operates on a closed regenerative thermodynamic cycle with cyclic compression and expansion of the working fluid (probably air) at different temperature levels. The flow of the working fluid is controlled by changes in the volume of the hot and cold spaces thereby eliminating the need for valves. The Stirling Engine is reversible, meaning that an input of heat energy (burning fuel say for example) will produce an output of mechanical energy, and an input of mechanical energy (electric motor, etc.) will produce an output of heat energy. In this manner, the Stirling Engine can be used as a heat pump in much the same way as traditional refrigeration units, only without the environmentally harmful refrigerants.

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The most basic engine consists of a set of pistons, heat exchangers, and a device called a 'regenerator'. The engine is filled with a working fluid (gas) which is commonly Air, but some more advanced engines may use Nitrogen, Helium or Hydrogen. The pistons are arranged such that they create both a change in volume of the working fluid and create a net flow of the fluid through the heat exchangers. Heat is absorbed from an external source in the 'hot' end, creating mechanical energy, and rejected in the 'cold' end to the environment.

STIRLING CONFIGURATIONS

The mechanical configurations of Stirling engines are generally divided into three groups known as the Alpha, Beta, and Gamma types.

Alpha

Alpha engines have two pistons in separate cylinders which are connected in series by a heater, regenerator and cooler. Both Beta and Gamma engines use displacer-piston arrangements, the Beta engine having both the displacer and the piston in an in-line cylinder system, whilst the Gamma engine uses separate cylinders.

Beta

Unlike the Alpha machine, the Beta engine has a single power piston and a displacer, whose purpose is to "displace" the working gas at constant volume, and shuttle it between the expansion and the compression spaces through the series arrangement cooler, regenerator, and heater.

Gamma

Gamma type engines have a displacer and power piston, similar to Beta machines, however in different cylinders. This allows a convenient complete separation between the heat exchangers associated with the displacer cylinder and the compression and expansion work space associated with the piston. Thus they tend to have somewhat larger dead (or unswept) volumes than either the Alpha or Beta engines.

REGENERATOR

The regenerator is where the excess heat of the gas is stored in the regenerator matrix on

Figure 1: An Alpha Stirling Engine Without Regenerator

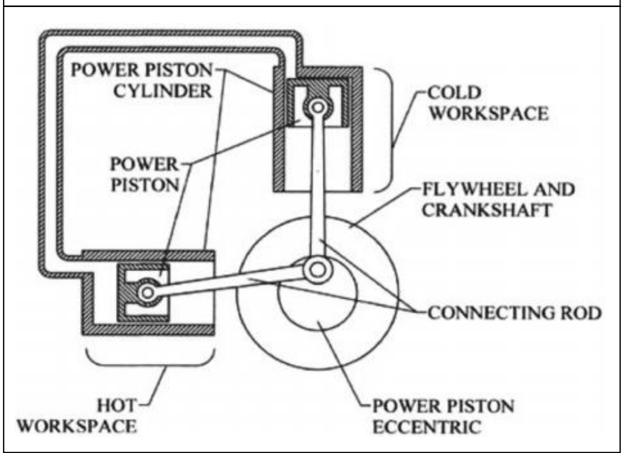
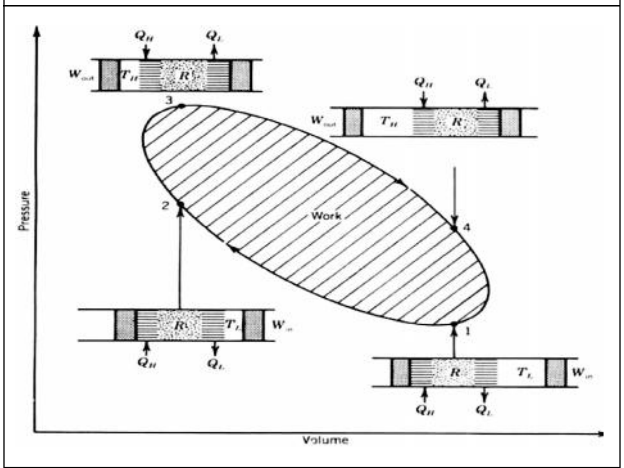


Figure 2: Actual P-V Diagram of an Alpha Stirling Engine

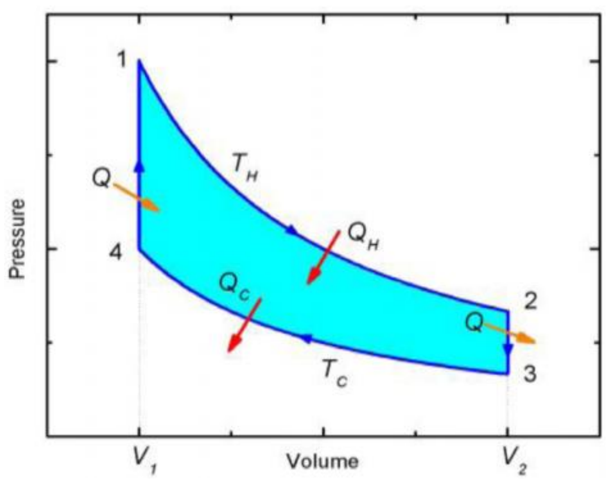


the way to the compression space from the expansion space and then the heat is recovered on the way back from the compression space to the expansion space.

Theory

The space above the hot piston is continuously heated by a heat source. The space above the cold piston is continuously cooled. Every Stirling engine has a sealed cylinder with one part hot and the other cold. The working gas inside the engine (which is often air, helium, or hydrogen) is moved by a mechanism from the hot side to the cold side. When the gas is on the hot side it expands and pushes up on a piston. When it moves back to the cold side it contracts. Properly designed Stirling engines have two power pulses per revolution, which can make them very smooth running. Two of the more common types are two piston Stirling engines and displacer-type Stirling engines. The two piston type Stirling engine has two power pistons. The displacer type Stirling engine has one power piston and a displacer piston.

Figure 3: Theoretical P-V Diagram of an Stirling Cycle with Various Processes Involved



It includes the four processes

1. Iso-thermal expansion process
2. Constant volume heat transfer process
3. Iso-thermal compression process
4. Constant volume heat removal process

Iso-Thermal Expansion

Process 1, 2: Isothermal Expansion

- Heat addition from high temperature heat sink.
- Work is done by the working fluid (energy exchange to flywheel).

The heat source causes the air in the hot cylinder to expand and thus pushes both the cylinders outward.this process is defined as process 1 in the cycle.

Constant Volume Heat Addition

Process 2, 3: Isochoric Heat Addition

- Heat addition (energy exchange from regenerator).
- No work is done.
- 2W3 = 0.

The gas has expanded (about 3 times in this example). Most of the gas (about 2/3) is still located in the hot cylinder. Flywheel momentum carries the crankshaft the next 90 degrees, transferring the bulk of the gas to the cool cylinder.

Iso-Thermal Contraction

Process 3, 4: Isothermal Compression

- Heat rejection to low temperature heat sink.
- Work is done on the working fluid (energy exchange from flywheel).

The majority of the expanded gas has shifted to the cool cylinder. It cools and contracts, drawing both pistons inward.

Constant Volume Heat Rejection

Process 4, 1: Isochoric Heat Rejection

- Heat rejection (energy exchange to regenerator).
- No work is done.
- 4W1 = 0.

The contracted gas is still located in the cool cylinder. Flywheel momentum carries the crank another 90 degrees, transferring the gas to back to the hot cylinder to complete the cycle.

WORK OUTPUT

The net work done over the cycle is given by:

$W_{net} = (W_{3\text{-}4} + W_{1\text{-}2})$.

where the compression work $W_{1\text{-}2}$ is negative (work done on the system) AS INDICATED IN THE P-V DIAGRAM

A measure of the regenerator effectiveness is given by Equation, with the value of e = 1 being ideal.

$$e = (T_R - T_L)/(T_H - T_L) \qquad ...(1)$$

where,

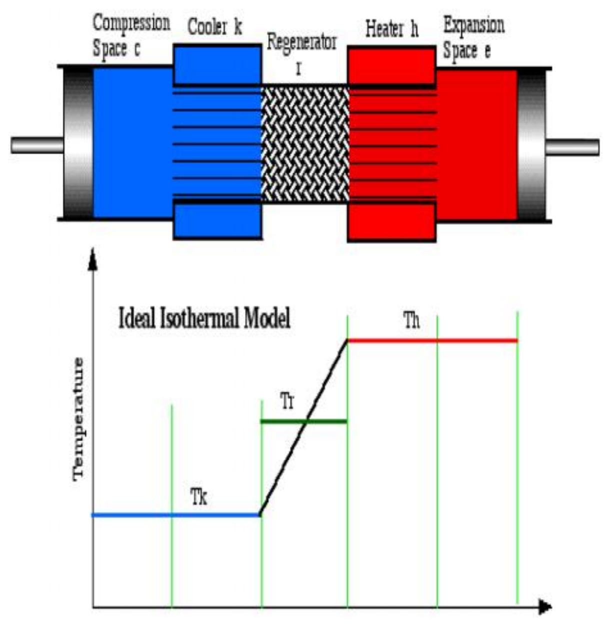
T_H = Temperature of high thermal sink.

T_L = Temperature of low thermal sink.

T_R = Mass averaged gas temperature of regenerator leaving during heating.

The cannot efficiency is denoted by Equation (2) and the real cycle efficiency with regenerator is denoted by Equation (3). Though regeneration is not required for a Stirling cycle, its inclusion can help improve the efficiency if applied properly. The regenerator efficiency does not tend to zero as the regenerator effectiveness tends to zero.

Figure 4: Temperature Distribution Across an Alpha Stirling



EFFICIENCY ANALYSIS AND RESULTS

Now PV-diagram of the Stirling engine shown in Figure 2 can be examined in detail. The key points are that during expansion along path 1-2 there is no temperature difference so that the change in internal energy $dU = 0$. From the first law of thermodynamics heat added from the hot reservoir is the same as the work done by the system, $Q_H = W_H$. Similarly, during the compression along path 3-4 there is also no temperature gradient so that $Q_C = W_C$. Therefore, the efficiency of an ideal Stirling engine is given by $EFFICIENCY = 1 - (W_C/W_H)$.

As stated above, the work W_C and W_H are given by the area under the curves $P = nRT_C/V$ and $P = nRT_H/V$ of the isothermal processes. It is difficult to obtain the area without resorting to calculus, however a simple geometric argument can be used to show that if area under the curve $y = 1/x$ is A, then the area under $y = k/x$ is kA. For the PV-diagram of the ideal Stirling engine if there is a curve $P = 1/V$ and the area under that curve is A, then the curve representing the isothermal Expansion $P = nRT/V$ will have an area of $nRTA$. Thus, the thermal efficiency of the ideal Stirling cycle will be

$$\textit{Efficiency} = 1 - (W_C/W_H) = 1 - (nRTcA/nRThA) = 1 - (T_C/T_H)$$

This equation gives the thermal efficiency of an ideal Stirling engine operating between temperatures T_H and T_C. This is the same efficiency obtained from an ideal Carnot cycle and is theoretically the maximum efficiency that can be obtained from any heat engine. It is clear that to increase the efficiency one should either use a very large T_H or a very low T_C refer Equations (3-4).

¦*carnot* $=1 - (T_L/T_H)$ ...(2)

¦*regenrator* is given by,

$(T_H - T_L)/(T_H + [(1 - e)/(CPCV - 1)]\ [(T_H - T_L)/\ln(V_1/V_2)])$ ...(3)

¦*regenrator* < ¦*carnot* ...(4)

Another major cause for inefficiencies of the real Stirling cycle engine is that not all of the working gas participates in the cycle, i.e., dead volume. The dead volume involves the volume that does not participate in the swept volume of the piston stroke. Martini (2004) states that the relationship between the percentage of dead volume in the system to the decrease in work done per cycle is linear. Therefore, if the engine has 20% dead volume then the power output would be 80% of the power that would be produced with zero dead volume. In actuality, dead space will always be present because the addition of internal heat exchangers, clearances, transfer tubes, and regenerators are required to enhance the heat exchange of the real system.

"In the mid 1800's a very bright Frenchman named Sadi Carnot figured out the maximum efficiency possible with any heat engine. It is a formula like this

(Temperature of the hot side – Temperature of the cold side)/Temp of hot side x 100

equals the max theoretical efficiency. Of course the temperatures must be measured in degrees Kelvin or Rankine. Stirling engines (with perfect regeneration) match this cycle. Real Stirling engines can reach 50% of the maximum theoretical value. That is an incredibly high percentage".

In Figure 1 isothermal model showing the temperature variations as considered for the simple analysis, it can be seen that for the real heater and cooler the mean effective temperatures in the heater and cooler are respectively lower and higher than the respective heat exchanger wall temperatures. This implies that the engine is operating between lower temperature limits than originally specified which effectively reduces the performance of the engine. The simple analysis for the heater and cooler iteratively determines these lower operating temperature limits by using the convective heat transfer equations. Values for the heater heat transfer (Qh) and cooler heat transfer (Qc) are obtained from the adiabatic analysis.

COMPUTER AIDED DESIGN OF STIRLING ENGINE AND PREDICTION OF POWER OUTPUT CHARACTERISTICS

Simple Performance Prediction Method for Stirling Engine ver. 1.8 J Koichi Hirata (March 31, 1998) (Table 1).

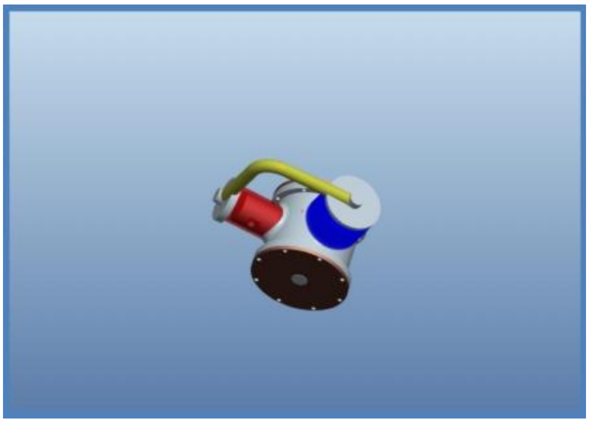
How to use this method?

- Please input or select a mean pressure, a swept volume, gas temperatures and a kind of the working gas on the calculated condition.
- When the engine is operated at the design pressure and the permitted temperature (maximum temperature), please check 'Use the design and permitted values'.
- If not so, please check 'Do not use the design and permitted values' and input the design pressure and the permitted temperature.
- Please click 'START'.
- Maximum output power and the engine speed when the engine get the maximum output power are calculated under the experimental equations.

Calculated conditions,

- Mean pressure, Pm: (MPa)
- Swept volume of expansion space, Vse: (cm3)
- Gas temperature of expansion space, Te: (deg C)
- Gas temperature of compression space, Tc:(degC)
- Working gas, He, Air, N2, H2.
- Design pressure, Plim: (MPa)

Figure 5: A Pro-e Model of an Alpha Stirling Engine



- Permitted temperature, Tlim: (Ž)
- Maximun output power, Ls: (W)
- Engine speed, N: (rpm)

Note: Description with Value Unit of our stirling engine model A-204 configuration considered

OPTIMUM SPECIFICATIONS OF AN A-204 STIRLING ENGINE

- Mean operating pressure Pmean 1.148 bar.
- Cold side wall temperature (Tc) 46 ºC.
- Hot side wall temperature (Th) 448 ºC.
- Operating frequency (i.e., speed) 73.3 rpm.

Analysis results of an A-204 stirling engine from an journal titled "*Description of Stirling Engine*" from Ing. Marek daniel, Doctoral Degree Programme, Dept. of Electrical Power Engineering, FEEC, Germany.

ADVANTAGES

The Silence of Operation: There is no expansion in the atmosphere like in the case of an internal combustion engine, combustion is continuous outside of the cylinders. In

Table 1: Analysis Results of an Stirling Engine

Method of Analysis	Gas Mass (g)	Power (W)	Efficieny (W)
Schmidt	0.66054	21.81	55.76
Adiabatic	0.672	16.2	42.1
Simple Thermal Analysis	0.6606	14.21	38.4

addition, its design is such as the engine is easy to balance and generates few vibrations.

The High Efficiency: It is function of the temperatures of the hot and cold sources. As it is possible to make it work in cogeneration (mechanical and caloric powers), the overall efficiency can be very high.

The Multitude of Possible "Hot Sources": combustion of various gases, wood, sawdust, waste, solar or geothermic energy...

The Ecological Aptitude: To respond to the Environmental requirements on air pollution. It is easier to achieve a complete combustion in this type of engine.

Reliability and Easy Maintenance: The technological simplicity makes it possible to have engines with a very great reliability and requiring little maintenance.

An High Lifetime: Because of no internal combustion.

The Very Diverse Uses: Because of its autonomy and adaptability to the needs and the different kinds of hot sources (from mW to MW).

MAJOR DRAWBACKS OF AN STIRLING ENGINE

Fails to Start Instantly

While it's very easy to build a Stirling engine that will stop instantly, there is not one thing in the world anyone can do to make one start instantly. When it is introduced in cars all we want is to start immediately (if not sooner) it will not be commercially appreciated. In spite of these limitations, Ford, GM, and American Motors Corp. spent millions of dollars developing Stirling engines for cars, back in the 1970's. Ford even built a Stirling engine that could drive away from the curb (with relatively low power) twenty seconds after you turned the start key! Many prototypes were built and tested. Then oil prices came down in the 1980's, and people started to buy bigger cars. Suddenly there was no compelling reason to build an engine that was substantially more efficient than internal combustion engines, but wouldn't start instantly. The Stirling is more efficient than the internal combustion or diesel engine, and it's also a lot quieter. Sounds great, but it's not good for cars because it can't revolve up quickly and it takes about 5 minutes to get the engine hot enough to run well. We want our cars to start the second we put the key in. In the ages of 1970's and 1980's several automobile companies like "General Motors" or "Ford" were researching about Stirling Engine. This device is good for a constant power setting, but it is a challenge for the stop and go of the automobile. A good car can change the power quickly. One possibility to obtain this important characteristic is design a power control mechanism that will turn up or down the burner. This is a slow method of changing power levels because is not enough to accelerate crossing an intersection.

Lack of Flexibility

The fast and effective variations of power are difficult to obtain with a Stirling engine. This one is more qualified to run with a constant nominal output. This point is a great handicap for an utilization in automobile industry.

Other Drawbacks of Using an Stirling Engine

- There is another engineering limitation to the manufacturing of stirling engines. Any common machine tools can have tolerance down to +/- 0.001 like we have here in the machine shop.
- Second, solar engines don't need to change power output quickly, they would be base load like wind power.
- One of the main draw backs of stirling engines is the cooling of a working fluid but generally they run on air which is rather plentiful.

MODIFICATIONS OF AN ALPHA STIRLING ENGINE WITH VENTURI BASED FLUID FLOW CONTROL SYSTEM

To Improve the Engine's Response Towards Speed Variation

The main drawback which doesn't allow this engine to be used commercially is that it gives out only nominal output. Fast and effective variations of power are difficult to obtain with this engine. To overcome this drawback and to make the engine reliable as an internal combustion engine, an idea of introducing a venturi and an expansion chamber in the regeneration pipe to vary the power output using the bernoulli's principle.

Figure 6: Modified Alpha Stirling Engine with an Venturi Based Working Fluid Control System

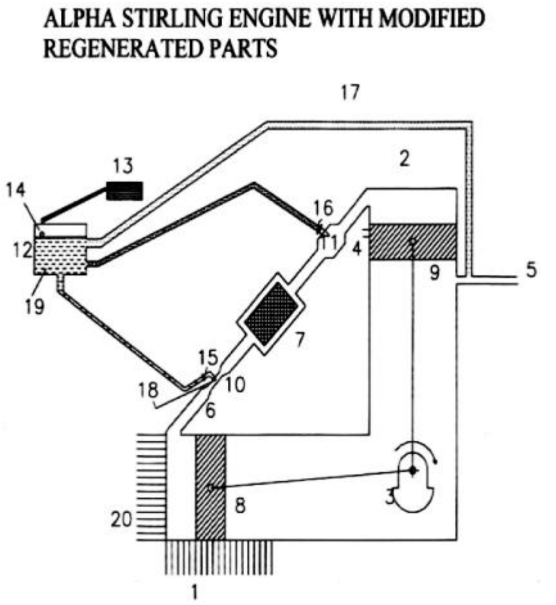
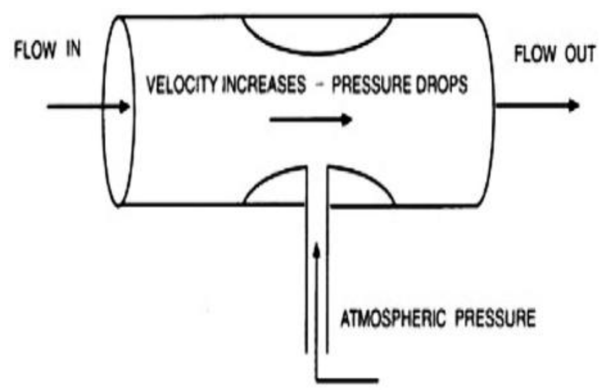


Figure 7: Parts Description of an Modified Alpha Stirling Configuration

1.HOT SIDE
2.COLD SIDE
3.FLY WHEEL
4.WATER IN
5.WATER OUT
6.REGENERATOR PIPE
7.REGENERATOR(WIRE MESH)
8.PISTON 1
9.PISTON 2
10.VENTURI
11.EXPANSION CHAMBER
12.W.F+WATER RESERVOIR
13.W.F RESERVOIR
14.FLOAT
15.SPEED INCREASE THROTTLE
16.SPEED DECREASE THROTTLE
17.WATER PIPE
18.NOZZLE
19.W.F+WATER MIXTURE
20.FINS(HOT SIDE)

Venturi works based on bernoulli's principle which states that, "According to the laws governing fluid dynamics, a fluid's velocity must increase as it passes through a constriction to satisfy the principle of continuity, while its pressure must decrease to satisfy the principle of conservation of mechanical energy. An equation for the drop in pressure due to the

Figure 8: A Simple Venturi Tube Which Plays a Vital Role in Pressure Variation (This Figure is Shown for Reference Only)



Venturi effect may be derived from a combination of Bernoulli's principle and the continuity equation." As per the ideal gas law equation it is proved that the working pressure of the fluid increases with increase in the mass of the fluid enclosed in a air tight chamber,

$PV = nRT$

where n is the number of moles which is defined as total mass in grams by the molecular weight of one molecule. As mass of the working fluid increases therefore the pressure of the fluid also increases.

Also a small quantity of working fluid is mixed with the preheated water which is obtained from the cooling tower so that the working mixture gains heat transfer coefficient.

Table 2: Heat Transfer Coefficient of Various Mediums Under Different Conditions

Fluid	Heat Transfer Coefficient (w/m^2k)
Free Convection, Air	5-28
Forced Convection, Air	10-500
Water	100-1700
Boiling Water	2500-57000
Condensation of Steam	5000-110000

The addition of boiling water to increase the rate of heat transfer as per the Newton's law of convection $Q = hA(T_1 - T_2)$ watts.

Also the volumetric efficiency of the engine can be increased as per the equation,

Volumetric Efficiency = Actual Mass of Working Fluid(m_a)/ Theoretical Mass of Working Fluid per Stroke (m_t)

Helium is used as working fluid for the following advantages,

- Thermal conductivity is high as molecular weight is less.
- Safer then hydrogen in terms of storage.
- No reaction when mixed with water.

To Promote the Quick Start of the Engine to Attain the Running Torque at Lesser Time by Modification of the Engine Parts

- The major problem that makes the engine handicap is that it takes some time for the engine to attain the running torque unlike other I.C engines which could pick up in just a less span of time.
- On a complete theoretical analysis of an alpha stirling engine on this scope, the actual problem is found among the engine thermal parts which plays the role of transfer of the external heat to the working fluid through convection. As per the newton's law of cooling or newton's law of convection it can be stated that $Q = hA(T_S - T_A)$ watts.

To increase the heat transfer to the working fluid through convection the heat transfer co-efficient of the working fluid should be high which is successfully done by introducing helium as the working fluid along with the small fraction of hot water from the cooling tower as discussed in the previous topic (refer table in previous topic).

- The walls of the cylinder are in circular cross section. Increasing inner and outer overall heat transfer co-efficient can be done based of the following equation for free convection of fluid inside a cylinder.

  $U_i = 1/((1/h_i) + (r_i/k) \ln(r_o/r_i) + (r_i/r_o)(1/h_o))$

  From the above equation the inner heat transfer co-efficient of the cylinder can be increased by increasing the h_i, h_o, k.

- To increase the heat transfer rate with respect to time an reverse idea of heat transfer by convection using fins in air cooled engine can be followed. In fins the surface area of the heat transfer is increased to increase the heat transfer by convection.

Thus, Fins are Used as Heat Absorbing Agents from the Heat Source and are Attached to the Cylinder Walls on the Hot Side of the Engine

The fin material used should posses a very high thermal conductivity which can be defined as the ability of the material to conduct heat through it. Thus on analyzing the possible materials theoretically based on their thermal properties the best results that are obtained are:

Copper-Nickel Alloys

- Melting Point = 1400-1630 °C.
- Thermal Conductivity (K) = 425-460 W/mk.
- Thermal Diffusivity = 119.34*10^-6 m^2/s.
- Specific Heat = 438 J/KG k.

Aluminium Alloy (in General)

- Melting Point = 690-1300 °C.
- Thermal Conductivity (K) = 205-430 W/mk.
- Thermal Diffusivity = 84-96*10^-6 m^2/s.
- Specific Heat = 840-920 J/KG k.

Table 3: Thermal Conductivity of Various Fin Materials

Material	Thermal Conductivity (K) W/mk
Silver (Pure)	407.0
Copper (Pure)	386.0
Aluminium (Pure)	204.0
Mild Steel (Pure)	37.2

From the above table it is clear that the silver has good thermal properties for our aspect, but due to its high cost it becomes unsuitable. The other choices are copper and aluminium. Thus on comparing both the materials it can be clarified that the aluminium(pure) has a very less melting point. Thus copper can be used. But in pure state it has very poor mechanical properties like tensile strength, hardness, etc., thus, any alloy of copper with nickel or chromium suits for this purpose.

Note: Using a cylinder material with good thermal diffusivity can increase the response of the engine towards the heat change. Since, thermal diffusivity is the fastness with which the heat can be propogated through the material.

Thus,Greater the thermal diffusivity of the material lesser the time taken by the heat to penetrate through it. Its unit is m^2/s.

SOLAR STIRLING ENGINE

An alternative and renewable fuel which is more easily available for generating electricity is solar radiations. stirling engines are rarely used with an solar collecting parabolic dish which collects the solar radiations falling on an wide area of the land and focus the highly intense radiations to a concentrated point thereby indirectly acting as an source of high temperature. Solar energy has been utilized before for power production in heat engines, however, most of the previous applications were for steam turbines that would be only practical for very large scale installations. Stirling engines provide a methodology for generating power for use.

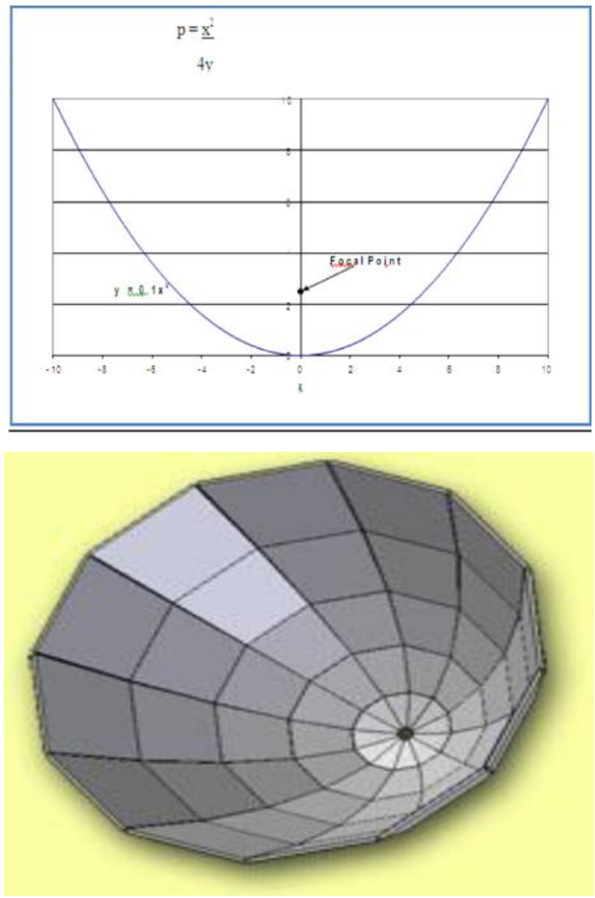
The schematic dish below illustrates a small scale electric power from solar thermal energy system which utilizes solar energy for stirling. In this system, the solar heat collector provides heat for the solar Stirling engine which in turn provides AC power. The electrical power can be transferred to a battery charger, then to DC control unit which can either go into a battery or into an inverter (Figure 9).

Efficiencies for this type of small scale system can range from 18% to 23% (in general). The scalar diagram below gives the basics of an parabolic reflector and the focal point,

An Solar Collector (i.e., Parabolic Dish) is Designed in Autocad Software and has been Presented Below for Reference

A wide variety of solar concentrators are currently commercially available in order to concentrate solar rays for the purpose of power generation. There are many forms of solar concentrators, but the most common forms are those which utilize curved, parabolic mirrors and those which use Fresnel lenses. Parabolic Troughs are the most widely used type of solar concentrator. It consists of a linear parabolic reflector which can concentrate sunlight onto a tube, commonly filled with a working fluid such as molten salt, and positioned along the focal length in order to generate heat for power generation.

Figure 9: Geometrical and Graphical Model of an Parabolic Solar Collector



This type of solar concentrator can be found in Solar Energy Generating Systems (SEGS) plants in California, Accionas Nevada Solar One, and Plataforma Solar de Almerias in Spain (Laboratories, 2009). SES solar Stirling engine, named Sun Catcher, was awarded the 2008 Breakthrough Award winner by Popular Mechanics for its role as one of the top 10 world-changing innovations. The Sun Catcher is a 25 kW solar dish Stirling system which uses a solar concentrator structure which supports an array of curved glass mirror which are designed to follow the sun and collect the focused solar energy onto a power conversion unit.

RESULTS AND DISCUSSION

Some results are obtained by theoretically studying the engine performance with the above mentioned modifications so the it gains improved features to make it commercially successful. Consider an engine running at high temperature T1 (say, around 773 K to produce 5 hp) with pressure (p1) at initial expansion condition. Depending upon the results obtained by the dynamic simulation of the model with the above mentioned modifications, it can be clearly discussed that,

- Thus the problem of slow start is reduced when compared to the model before, so that the engine attains the running torque in a less span of time.
- The power output of the engine can be varied flexibily without much damage to the engine parts.

The heat source of this engine can be of any type like solar (renewable), nuclear, burning of wood, rice husk, exhaust heat of the chimneys, combustion of biogas, etc., unlike conventional engines (IC engine) this engine has got a smooth running and less noisy operation which makes it more advantageous mechanically. By incorporating the modifications to eliminate the drawbacks as much as possible using modern production methods. The stirling engine of alpha type can be used to the following applications provided that it is successfully modified as per the above explained altrations. The modern Stirling Engine is a clean and efficient engine. This is because the heat driving the pistons is supplied from outside the engine and transferred through heat exchangers to the piston volumes. Thus the addition of pollutants such as NOx to the environment can be avoided. The external combustion aspect enables a Stirling Engine to operate equally well on multiple types of fuel, such as natural gas, propane, gasoline, diesel, ethano-l85, bio-diesel or even heat from the sun. The extra quiet operation of the Stirling Engine is one of the engines best features. Many Stirling engine configurations are balanced by the nature of their construction, and since the fuel is burned slowly and constantly outside the engine, there are no explosions to muffle. This power capacity will be achieved via the use of a solar concentrator large enough to supply the hot end with sufficient heat and by generating a cold end which can efficiently dissipate heat into the atmosphere or working fluid in order to produce the needed change in temperature to create the volume changes in the cylinder. The efficiency of the engine can be maximized by selecting appropriate fins and extended surfaces as well as accurately focusing sunlight on the hot end. Other important consideration when designing a solar Stirling engine is to take into account the locations of where the engine will be placed, since the sunlight reaching the engine is dependent on its location on the globe. Along the same lines, allotting adequate space without coverage from trees and building so that the sunlight reaching the engine is not blocked.

CONCLUSION

The stirling engine is considered as an eco-friendly and user friendly engine since, it has

Table 4: List of Industrial Heat Wastes and their Temperature Limits

Type of Device	Temperature (°C)
Steam Boiler Exhausts	230-480
Gas Turbine Exhausts	370-540
Reciprocating Engine Exhausts	315-600
Reciprocating Engine Exhausts (Turbo Charged)	230-370
Heat Treating Furnaces	425-650
Drying and Baking Ovens	230-600
Catalytic Crackers	425-650
Annealing Furnace Cooling Systems	425-650

no exhaust gases coming out of the engine after each power cycle with toxic emittents which makes this engine much better *n* terms of working and maintenance. Also, the engine requires a very less maintenance than conventional SI, CI engines provided that if proper lubrication is done.

- Excellence in power production using solar heat.
- Reducing the cost of electricity since it is produced from an renewable source (like solar). Thus promoting the usage of electric locomotives.
- Utilization of these engines from industrial heat exhaust and to convert the same into power.
- Medium power machineries can be operated with the aid of this engine since the power variation may be possible.
- It could provide as world's major power source when the entire oil resource of the world is completely harvested.

Thus a theoretical simulation of a thermodynamic model of alpha type stirling engine is successfully done with some modifications of the parts in order to prove a better variation in the engine's output, thus making the engine to meet with the commercial requirements successfully.

REFERENCES

1. Abdul Rahman A S (2011), "Selection and Experimental Evaluation of Low-Cost Porous Materials for Regenerator Applications in Thermo Acoustic Engines", *Materials & Design*, Vol. 32, No. 1, doi: 10.1016/j.matdes.2010.06.012
2. Energy Conversion (2010), *In Encyclopedia Britannica*, Retrieved September 22, 2010, www.britannica.com
3. Hargreaves C M (1991), *The Philips Stirling Engine*, Elsevier Science Publishers, New York.
4. Hooper C and Reader G T (1983), *Stirling Engines*, Cambridge University Press.
5. Kroliczek E J, Nikitkin M and Wolf D A (2010), US Patent No. 7,708,053, US Patent and Trademark Office, Washington DC.
6. Solar-13 Stirling Engine Model (2010), retrieved from http://www.pmresearchinc.com/store/product.php?productid=3101&cat=5&page=1
7. Stirling Engines (2010), *In Access Science*, Retrieved September 22, 2010, www.accessscience.com
8. Urieli I (2010), *Stirling Cycle Machine Analysis*, September.