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Design and Fabrication of Regenerative Heat Exchanger for Alpha Stirling Engine

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Abstract

This paper describes a new approach to Designing and fabrication a regenerative heat exchanger for Stirling engines with the goal of building a working prototype. The Stirling cycle is recast as a dynamic system where control design tools and techniques can be applied to determine optimal manufacturable parameters for the engine. This Alfa type Stirling engine constructed by two unused Kirloskar diesel engine as one is for power cylinder and another is for cooled cylinder. Both are coupled by two ways – one is flexible coupling and another is injector holder to heat exchanger joining by pressure pipe. This type of engine has a high power to volume ratio but has technical problems due to the usually high temperature of the hot piston and the durability of its seals. In a Stirling engine, the regenerator is an internal heat exchanger and temporary heat store placed between the hot and cold spaces such that the working fluid passes through it first in one direction then the other. To support one component of the model, a regenerative heat exchanger is described using a lumped parameter, nth-order model generalizable to an arbitrary number of sections within the regenerator dependent on its physical aspect ratio. Finally, the heat exchanger model is experimentally verified.

Keywords Alpha Stirling Engine, Regenerative heat exchanger, Design and fabrication, Experimental validation

Introduction
Stirling engine provide clean, reliable, mechanical power when provided only with a temperature gradient. Unlike combustion engine, Stirling engines do not require a distillate fuel like gasoline and can therefore streak on heat from any source such as geothermal, solar, biomass or nuclear vitality. The Stirling cycle operates by shuttling a compressed gas between two chambers separated by a lightweight piston.

The engine cycle is thrust by the transport of heat across a static temperature difference either side of the chamber. [1] Stirling Engine is a heat engine operating by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work.

Alpha Stirling engine
An alpha Stirling contains two power pistons in separate cylinders, one hot and one cold. The hot cylinder is situated inside the high temperature heat exchanger and the cold cylinder is situated inside the low temperature heat exchanger. This type of engine has a high power-to-volume ratio but has technical problems due to the usually high temperature of the hot piston and the durability of its seals. In practice, this piston usually carries a large insulating head to move the seals away from the hot zone at the expense of some additional dead space.

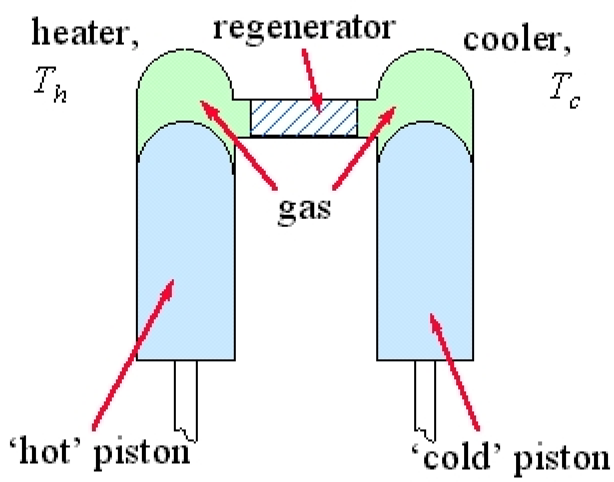


Figure 1: Alpha Stirling engine

Problem statement
We have tried to develop an alpha type Stirling engine by coupling two diesel engines at a phase difference of 90degree. Thus we have tried to develop an engine that is:

- Readily available in marked and thus easily replicable.
- The spares of engine would be easily available.

- The manufacturing difficulties that arise in developing a new engine are avoided.
- The engine can be easily reproduced in larger numbers if the experimental trials are successful.
- A regenerative heat exchanger is developed with specific case to prevent operating failure due to thermal cracking, leakage losses. Also efficient in heat transfer.

Project description

The key principle of Stirling engine is-"A fixed amount of a gas is sealed inside the engine. " Heat engine such as the Stirling engine is one that utilizes environmental heat to create a repetitive motion. In Stirling engine, cyclic expansion and contraction of the gas within the engine causes a piston producing mechanical work. Also, engine has no need for fan, electrical system or other engine types. Compared to the cost of other types of alternative energy such as nuclear power, wind power, and photovoltaic power the cost of producing Stirling engine is extremely low.

The primary effect of regeneration in Stirling engine is to increase the thermal efficiency by 'recycling' internal heat which would otherwise pass through the engine irreversibly. As a secondary effect, increased thermal efficiency yields a higher power output from a given set of hot and cold end heat exchanger. It is these which usually limit the engine's heat throughput. In practice this additional power may not be fully realized as the addition "dead space" (unwept volume) and pumping loss inherent in practical regenerators reduces the potential efficiency gains from regeneration.

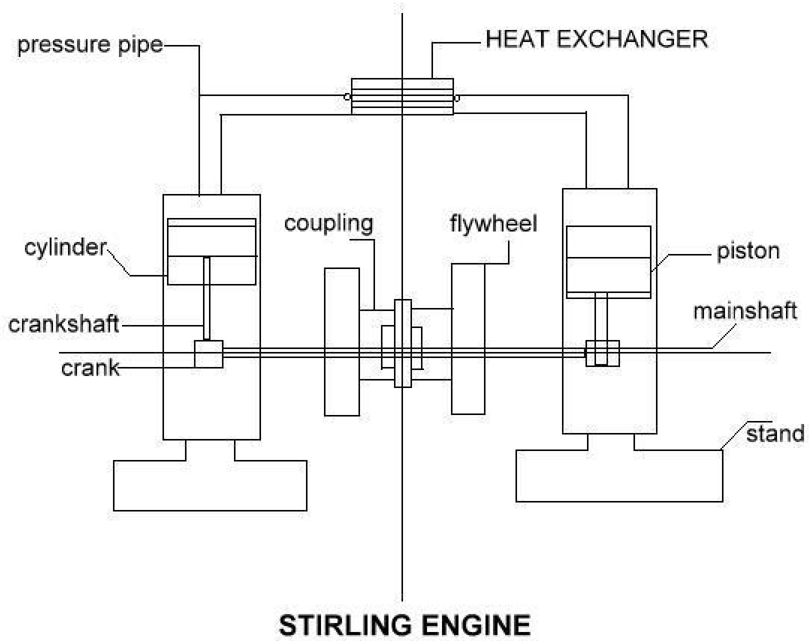
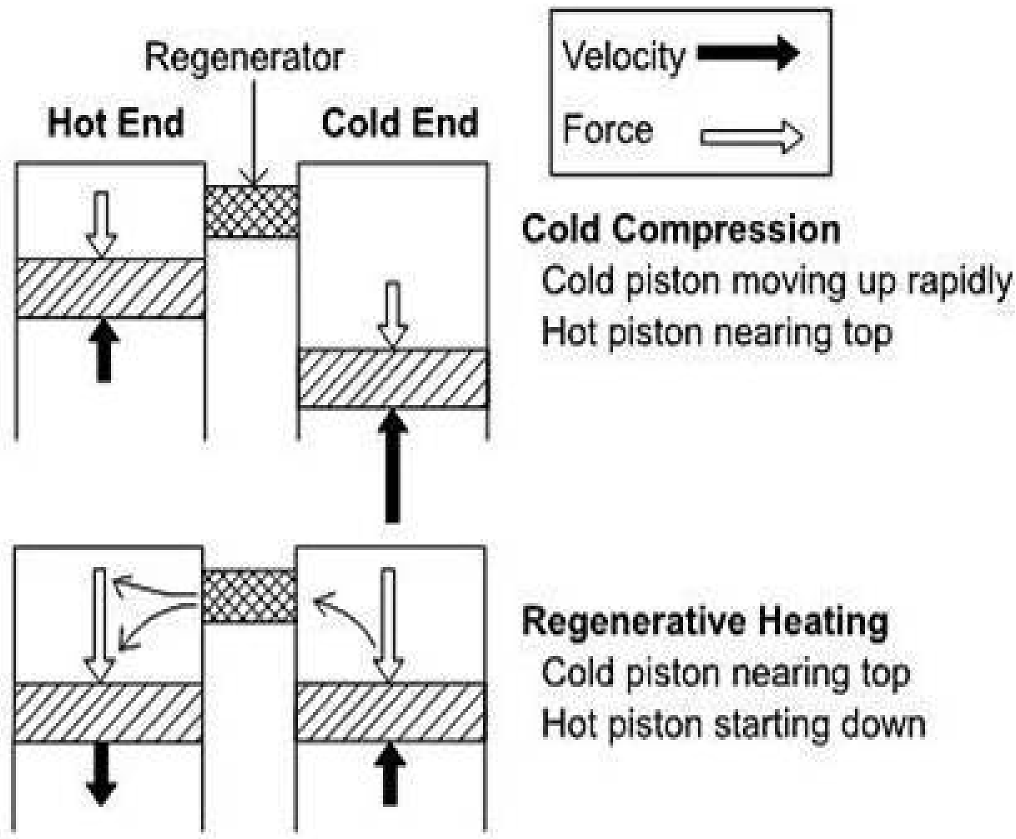


Figure 2: layout of Stiling engine

The design challenge for a Stirling engine regenerator is to provide sufficient heat transfer capacity without introducing too much additional internal volume or flow resistance. These inherent design conflicts are one of many factors which limit the efficiency of practical Stirling engine. A typical design is a stack of fine metal wire meshes, with low porosity to reduce dead space, and with the wire axes perpendicular to the gas flow to reduce conduction in that direction and to maximize convective heat transfer.

Process of working

Stirling engine s feature a completely closed system in which the working gas (usually air but sometimes helium or Hydrogen) is alternately heated and cooled by shifting the gas to different temperature locations within the system. Stirling, one cylinder is kept hot while the other is kept cool. In this illustration, the lower-left cylinder is heated by burn fuel. The other cylinder is kept cool by air circulating through a heat sink. Figure 3 illustrates the four phases of the Stirling cycle, which are somewhat analogous to the compression, power, exhaust, and intake strokes of the Otto cycle. In this illustration, it is assumed that the two pistons are mechanically linked to hold a fixed phase lag between the hot terminal and the cold end of the engine.



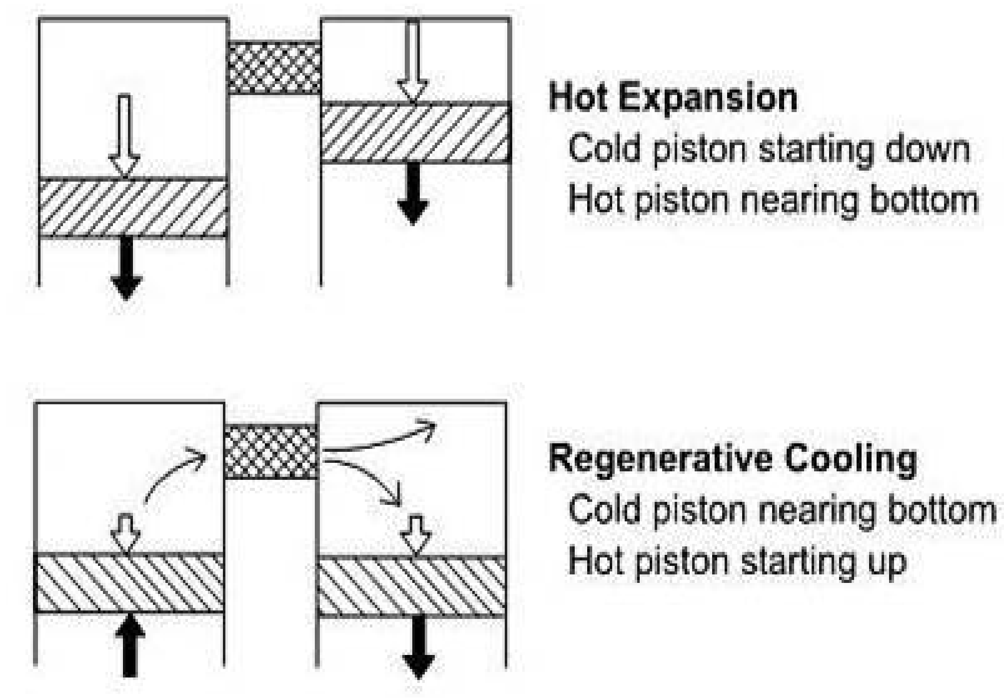


Fig 3 four phases of Stirling engine

Regenerator design consideration

A regenerative warmth heat exchanger, or more commonly a regenerator, is heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid. To accomplish this hot fluid is brought into contact with the heat storage medium, and then the fluid is displaced with the cold fluid, which absorbs the heat. In regenerative heat exchanger s, the fluid on either side of the heat exchanger can be the same fluid. The fluid may go through an external procedure step, and then it is flowed back through the heat exchanger in the opposite direction for further processing. Usually the application will use this process cyclically or repetitively. [3]

When designing the heat exchanger the following quantities have to be known

- The air inside the engine should get heated to high temperature of the order of 800^0 C and to provide high work output.
- The regenerator medium should get heated to a temperature higher than 800^0 C by the hot flue gases.
- The heat exchanger should have mechanical strength under high temperature high pressure.
- The thermal storage medium in heat exchanger should be uniformly heated thus should have uniform passages across cross section for passing flue gases.
- Should have minimum flue gas loss to have higher energy conversion efficiency.

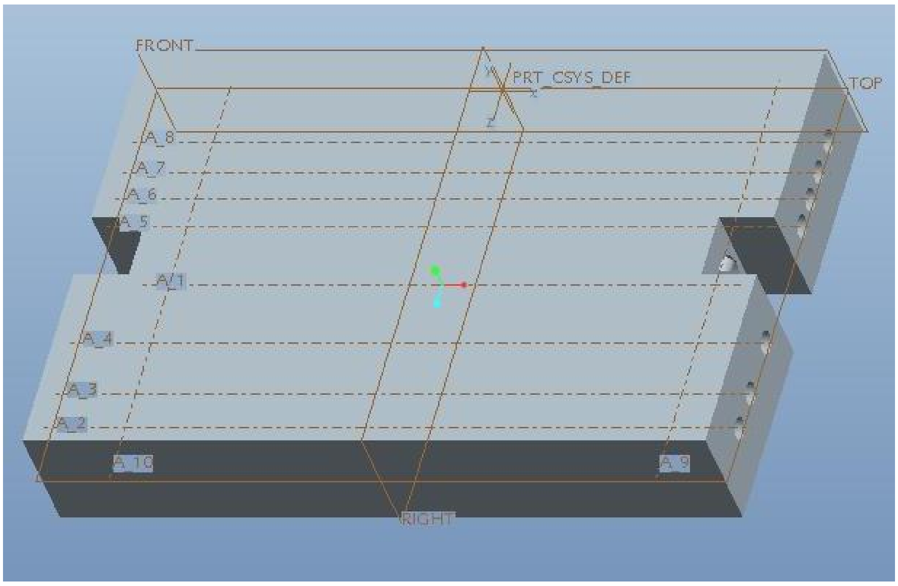


Figure 4: Computer generated diagram of regenerator

Heat exchanger fabrication

When selecting a heat exchanger material, some points should be taken into considerations like the type of fluids (media), application, and the temperature. Heat exchanger is fabricated from MS metal block. An MS metal block of required dimensions is used for it. Design parameters and conditions were same. The difference from shell and tube heat exchanger is that here pressure tubes are replaced with narrow drilling holes (5mm) So that there will no chance of any thermal cracking. The holes (5mm) are drilled parallel in the direction of air.

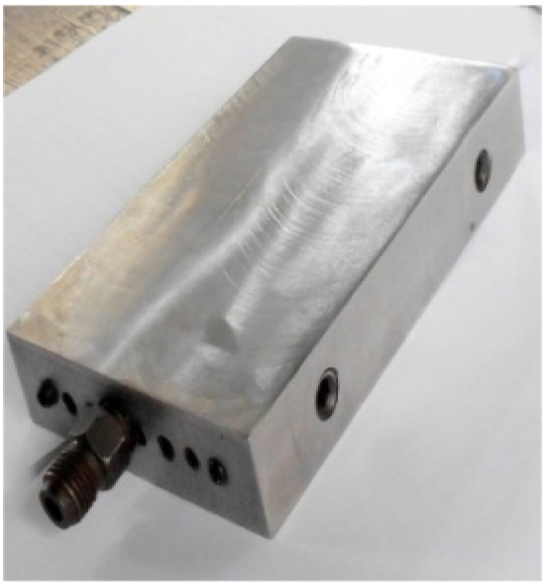


Fig – 4 fabricated regenerative heat exchange

Experimental validation and characterization

Both cylinder pistons are connected on 90^0 phase angle with the help of flexible coupling. The heat exchanger is heated heat exchanger. The engine consists of four thermodynamic processes action on the working fluid: which are as – expansion, transfer, contraction and transfer. When hot gas is transferred to the cool cylinder, it is first driven through the regenerator (heat exchanger), where a portion of the heat is deposited from LPG directly up to red hot condition. The temperature of heat exchanger reached over 600^0 C. First cylinder heated and another kept too cooled via water drops. After heated at certain level engine has cranked manually by hand cranking. When the cool gas is transferred back, this heat is reclaimed; thus the regenerator "pre heats" and "pre cools" the working gas, dramatically improving efficiency. Regardless of the function the heat exchanger fulfills, in order to transfer heat the fluids involved must be at different temperatures and they must come into thermal contact. Heat can flow only from the hotter to the cooler fluid.

Calculations for swept volume-

Table 1: Crank angle and total volume

θ	θ in radians	β	Stroke length (L)	Swept volume V1	Swept volume V2	Clearance volume	TOTAL VOLUME
0	0	0	0	0	597467. 5	58875	656342. 5276
15	0. 261792	0. 129769711	3. 053324	23980. 04	710368. 4	58875	793223. 403
30	0. 523583	0. 252673349	11. 8483	93053. 62	799756. 3	58875	951684. 9582
45	0. 785375	0. 361358369	25. 32252	198876. 7	865285. 7	58875	1123037. 459
60	1. 047167	0. 447823831	41. 83141	328533. 5	909234. 5	58875	1296642. 926
75	1. 308958	0. 50402957	59. 39139	466445. 1	934312. 9	58875	1459633. 072
90	1. 57075	0. 523598775	76. 07417	597467. 5	942450	58875	1598792. 527
105	1. 832542	0. 504043262	90. 44958	710368. 4	934324. 5	58875	1703567. 876
120	2. 094333	0. 447849528	101. 8311	799756. 3	909258. 6	58875	1767889. 943
135	2. 356125	0. 361393388	110. 1749	865285. 7	865324. 1	58875	1789484. 883
150	2. 617917	0. 252714784	115. 7707	909234. 5	799811	58875	1767920. 455
165	2. 879708	0. 129814839	118. 9639	934312. 9	710440. 2	58875	1703628. 162
180	3. 1415	4. 63268E-05	120	942450	597554. 8	58875	1598879. 846
195	3. 403292	-0. 129724583	118. 9654	934324. 5	466542	58875	1459741. 474
210	3. 665083	-0. 252631912	115. 7738	909258. 6	328630	58875	1296763. 658
225	3. 926875	-0. 361323347	110. 1797	865324. 1	198961. 8	58875	1123160. 953
240	4. 188667	-0. 44779813	101. 8381	799811	93116. 82	58875	951802. 7989
255	4. 450458	-0. 504015872	90. 45873	710440. 2	24013. 66	58875	793328. 8998
270	4. 71225	-0. 52359877	76. 08529	597554. 8	0. 012136	58875	656429. 8587
285	4. 974042	-0. 504056951	59. 40372	466542	23980. 04	58875	549397. 0008
300	5. 235833	-0. 447875221	41. 84371	328630	93053. 62	58875	480558. 6736
315	5. 497625	-0. 361428404	25. 33335	198961. 8	198876. 7	58875	456713. 5291
330	5. 759417	-0. 252756218	11. 85635	93116. 82	328533. 5	58875	480525. 2698
345	6. 021208	-0. 129859965	3. 057605	24013. 66	466445. 1	58875	549333. 8092
360	6. 283	-9. 26536E-05	1. 55E-06	0. 012136	597467. 5	58875	656342. 5397

Stroke length: L = (1-cos β) + (1-cosθ)
In triangle
r sinθ = l sin β
then β = sin-1(r sinθ / l)

Total volume = $\frac{\pi}{4}D^2$L + Clearance volume
And assume that
Total volume /clearance volume = Compression ratio
Here connecting rod length (l) = 120 mm and
Crank radius (r) = 60 mm

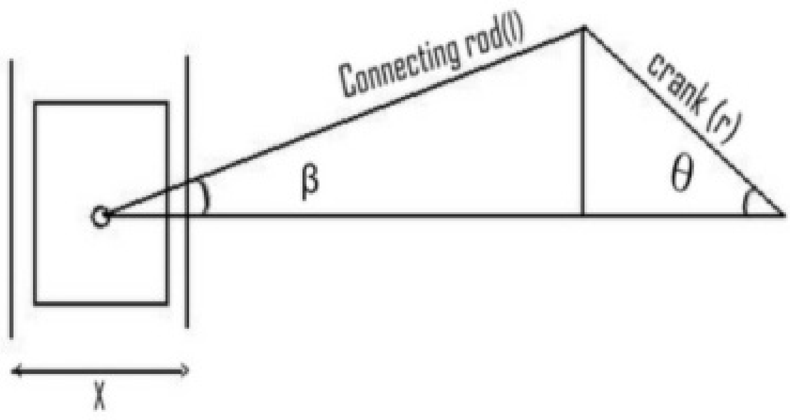


Fig 5 connecting rod and crank

Total volume vs crank angle graph

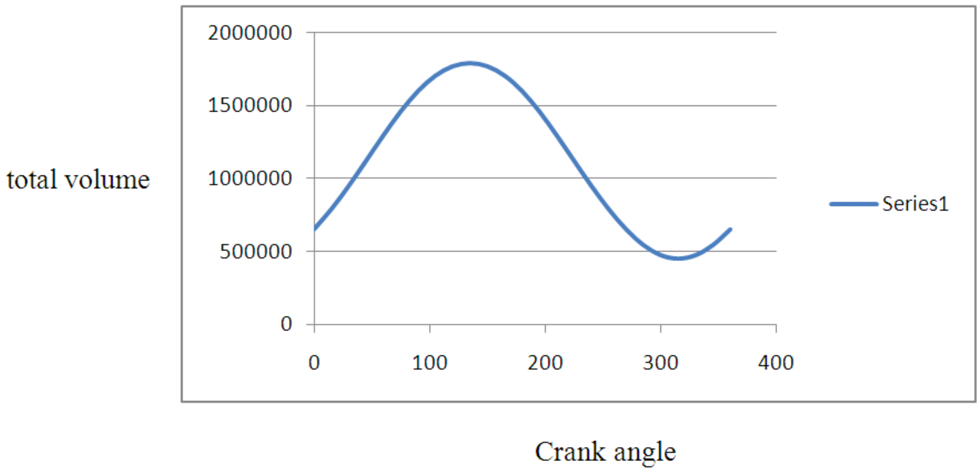


Fig. 6 plot between crank angle and total volume

Conclusion

Heat exchanger has attended the temperature of 600^0 C and no leakage was observed. No air bubble was formed on the cold side of the heat exchanger. Regenerative heat exchangers improve system efficiency by returning energy to the system. More trials will be performing on higher temperature for running the engine. Endurance trial would be carried out for the heating of more than 10 hours. Ceramic coating can be used as an insulator.

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