International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 4, July-Aug-2021, ISSN (Online): 2395-566X

Review Articles of Piston Designing Methodology and Optimization of its Performance

M. Tech. Scholar Rajesh Jamra, Asst. Prof. Dheeraj Shriwas, Associate Prof. Devendra Singh Sikarwar
Department Mechanical Engineering
Patel College of Science and Technology
Indore,MP,India

***Abstract*-In this paper gives a review of various piston design approach and provide a summary of conceptual design method previous research articles. For purpose of paper to collection of Literature review of related to piston designing contrast to designing drawback and different type of material optimization problem. To identification and observation of piston design method, Materials optimization suitable to piston designing with its performance evaluation see paper section-II summaries of algorithm of piston design.**

***Keywords*- Free Piston Stirling Engine, Particle Swarm Optimization, Dominant Poles.**

I. INTRODUCTION

Today, the pistons designed by the suppliers based on load data determined by the engine performance targets. From this data the supplier estimates the temperatures of the piston and recommends a design that is suitable for the application. This procedure is successful for the design of the piston, but gives no knowledge of the thermal interaction between the piston and its surrounding parts. The current trend in car engine development is to make smaller engines with higher specie power outputs to meet the demands for lower fuel consumption and emissions.

This leads to higher thermal loads on the engine and an increasing need to understand the heat balance of the complete engine in order to optimize the different engine parts and systems. A substantial part of the heat generated by the combustion is transported to the coolant through the piston and to the surrounding structure.

It is therefore important to get an accurate description of these interactions. The goal of Volvo Cars future combustion engine development is to increase power and efficiency and decrease fuel consumption while still maintaining reliability and durability of the highest possible level. As such, it is necessary to have a complete image of the thermal effect and how this acts the engine properties.

1. Purpose:

The main purpose of this Master's thesis is to provide a richer understanding on the subject of how to model heat transfer in a diesel piston and between the piston and the surrounding cylinder liner by delivering an extensive report and a reliable and thorough modelling methodology. The modelling technique is then to be implemented in a Finite Element model of a complete engine, but may also in future research beyond scope the of this Master's thesis be applied to a Computational Fluid Dynamics engine model.

2. Limitations:

The thermal analysis will be solely conducted through FE-analysis. The results of the FE-analysis will be validated through previous measured thermal test data the piston manufacturer Mahle. The software used for the thermal analysis will be ANSYS, since these are the software available. The Master's thesis is limited to only the thermal interaction between the piston and the cylinder liner with regard to the combustion, the engine coolant ow and the oil cooling mechanism. No other engine components will be considered in this Master's thesis. The Master's thesis will not evaluate fatigue, fracture, deformation or stresses of the piston or the cylinder. The tenement of the results and simulationsare limited to the computational capacity available at Chalmers University of Technology and at Volvo Cars Corporation. As this Master's thesis comprises of 30 HP the time frame is limited to the spring semester of 2015 for completion.

3. Prerequisites:

Volvo Cars did not have a thermal analysis model of diesel pistons prior to this Master's thesis work. The relevant data available for this thesis were the combustion load data from CFD-simulations and diesel piston temperature measurements.

4. Approach:

The temperature field of the diesel piston is solved iteratively according to the Inverse Heat Conduction method, presented in [1], combined with Finite Element analysis. The initial heat transfer coefficients of the diesel piston used in the iterative procedure of the Inverse Heat Conduction Method are calculated with analytical methods, empirical correlations, numerical methods and qualified assumptions. The Inverse Heat Conduction

Method is used in two steps in order to calculate the temperature field of the piston such that certain node temperatures of the FE-model correlate with the corresponding measurement data points and such that the heat flux across the piston boundaries are of magnitudes determined by the piston manufacturer Firstly, the heat transfer coefficients of the convective boundary conditions in a 2D asymmetrical piston FE-model are calculated iteratively with an in-house developed MATLAB code that utilizes the Inverse Heat Conduction Method.

Secondly, the determined heat transfer coefficients from the 2D asymmetrical parameter calibration are used as initial heat transfer coefficients when applying the Inverse Heat Conduction Method on a complete 3D piston FE-model. The parameter calibration software used for the second step is mode Frontier and the FE-analysis is performed with Abaqus and ANSA as pre-processor [2].

5. Theory:

An extensive literature study on thermal energy science was performed for the purpose of acquiring deeper knowledge in the field of diesel piston thermal analyses. General thermal energy- and species theories for internal combustion engines and pistons were evaluated.

An in-depth investigation of how Finite Element analysis can be utilized for a thermal problem was also performed. Analytical, empirical and numerical applicable approaches will be presented in this chapter giving an understanding of the physics and solution methodology of the piston thermal analysis [3].

II. LITERATURE REVIEW

Jihai Jiang, Kelong Wang [1] Due to their compact and simple design, axial piston pumps are widely used in hydraulic systems. The piston/cylinder lubricating interface is one of the most critical design elements in axial piston pumps, which fulfils the bearing and sealing function simultaneously. Also it is the main source of both friction and volumetric power loss. In order to realize the optimal design of efficient and reliable axial piston pump, an accurate model of the tribological interface in axial piston pump is needed to save the cost and time in the design process.

This study is aimed at developing a comprehensive simulation tool to model the lubricating gap flow between the piston and cylinder, which consists of a main flow model according to a lumped parameter approach and a numerical model for piston/cylinder interface.

The instantaneous pressure in each displacement chamber is obtained from the main flow model and utilized in the numerical model as an important boundary condition. An adaptive mesh is built for the oil film between piston and cylinder, on which the Reynolds equation is solved to get the pressure field. Also with the force balance check, the micro motion and gap height distribution is obtained. Couette flow, Poiseuille flow and squeeze flow are included in this numerical model. The simulation model proposed in this paper can provides a theoretical guidance for the structural design of axial piston pump [1]

Shengjun Wu, Zihao Cheng[2] Piston is the main component of the engine. In the engine work process, pistons need withstand both the instantaneous high temperature heat load and the mechanical load during the reciprocating process. The coupling between the thermal load and the mechanical load leads to the malfunction occurrence [2] of piston deformation, piston pin boss cracking, piston side wear, and top thermal cracking caused by the uneven temperature.

Therefore, pistons should have sufficient strength, stiffness, heat resistance, good thermal conductivity, small expansion coefficient and other properties. The reliability of pistons determines the reliability level of internal combustion engines. To improve the reliability level of the internal combustion engine, conducting the structural strength analysis of pistons to meet the design requirements is essential. The aided design model of the finite element software has been applied by many manufacturers [3]-[4].

Jigui Zheng, Ye Deng[3] Compact structure and high working efficiency are the characteristics of free Stirling linear generation device, whose power piston support components works in high frequency to produce elastic stiffness and to support the piston components. The structure of the power piston support components of free piston linear generator is designed.

The mechanical properties of power piston are analyzed by finite element analysis method, and the experiment for the verification of stiffness is finished. The power piston support components are applied to the free piston linear Stirling generator, and the experiment shows that the operating performance is very well [5].

Wu, Yi Zeng, Dongjian[4] The study of using DME as an alternative fuel on diesel engine started at early 90s. Experiments using DME as combustion fuel on all kinds of diesel engines done at Xi'an Jiao tong University and Shanghai Internal Combustion Engine Research Institute show that DME can achieve high efficiency, ultra-low emission, gentle, non-smoker combustion and meet the stringent Euro III and California ULEV standard[1].

However, there is no thermal load analysis research done for DME fuelled diesel engine parts, particularly piston, which as an important part in engine, has the character of large heat affected area and difficult to release heat. The structure and performance has significantly high impact on the power, economy and emission of the engine.

Therefore, it is important to analysis the thermal load of piston in DME fuelled diesel engine to make burning DME in diesel engine variable.

Shcherbachev Pavel [5] The article describes the electro-hydraulic rotary motion drive with separate control of piston groups. Proposed various schemes of construction of the drive. It is shown that the proposed actuator has a wide range of speeds, can work in tracking the position and speed of the output shaft. A nonlinear mathematical model of the drive is represented. The results of numerical simulation and experimental data are shown. The method of synthesis of a special control signal, which increases the efficiency of the drive is given.

O.F. Nikitin[6] This paper deals with the regulation of hydraulic parameters of movement of the output link (total stock) speed **-** load V = f (R) when using multiple cylinders, with a hard or serial connection rods. The required speed of movement is performed by connecting the required number of effective working areas of hydraulic cylinders. Change in the effective speed while maintaining the load may lead to changes in pressure in the cavity involved in the work of the hydraulic actuator.

Control parameter **-** the relative magnitude of the total effective working area of the piston cylinder involved in the reported time in the work, to the sum of the effective areas of the piston, available as part of the hydraulic drive. With the change (eg, decrease) of the speed of common stock in accordance with the change (increase) of the effective working area of the connected cylinders surmounted total load power can be increased at an aggregate stock at discharge pressure, if the permissible one is not exceeded, ie there is the opportunity to work with a constant power hydraulic drive.

The total value of the load can be much more than you can overcome with one cylinder without increasing the total amount of pressure in the system with a corresponding change in speed while maintaining a given flow rate. The set of 7 relative performance curves = f (VL) in the relationship of piston areas 1: 2: 4 of the three hydraulic cylinders is 7 straight lines of varying length

Guo Feng, Zhao Chang-lu[7] This paper investigates the piston motion control strategies of a single piston hydraulic free-piston diesel engine, which is intended to be a power supply for hydraulic propulsion systems. The Cycle fuel mass is determined by engine displacement and load.

A closed loop control method is used in fuel injection timing control strategy to make the position of bottom dead centre steady possibly. In each cycle, the injection timing is corrected by the compare between real bottom dead centre position and designed bottom dead centre position. The test results indicated that the advanced fuel injection control presented in this paper could improve engine performance and operational stabilization.

Isam Jasim Jaber and Ajeet Kumar Rai[8] In this present work a piston and piston ring are designed for a single cylinder four stroke petrol engine using. Complete design is imported to ANSYS 14.5 software then analysis is performed. Three different materials have been selected for structural and thermal analysis of piston. For piston ring two different materials are selected and structural and thermal analysis is performed using ANSYS 19 software. Results are shown and a comparison is made to find the most suited design.

Lokesh Singh, Suneer Singh Rawat[9] A piston is a component of reciprocating engines. Its purpose is to transfer force form expanding gas in the cylinder to the crank shaft via piston rod and a connecting rod. It is one of the most complex components of an automobile. In some engines the piston also acts as a valve by covering and uncovering ports in the cylinder wall. In present, work a three-dimensional solid model of piston including piston pin is designed with the help ANSYS software.

The thermal stresses, mechanical stresses and couples thermo-mechanical stresses distribution and deformations are calculated. After that fatigue analysis was performed to investigate factor of safety and life of the piston assembly using ANSYS workbench software. Aluminium-silicon composite is used as piston material. The stress analysis results also help to improve component design at the early stage and also help in reducing time required to manufacture the piston component and its cost.

Michaël De Volder, Frederik Ceyssens[10] Future micro robotic applications require actuators that can generate a high actuation force in a limited volume. Up to now, little research has been performed on the development of pneumatic or hydraulic micro actuators, although they offer great prospects in achieving high force densities. In addition, large actuation strokes and high actuation speeds can be achieved by these actuators.

This paper describes a fabrication process for piston-cylinder pneumatic and hydraulic actuators based on etching techniques, UV-definable polymers, and low-temperature bonding. Prototype actuators with a piston area of 0.15 mm2 have been fabricated in order to validate the production process. These actuators achieve actuation forces of more than 0.1 N and strokes of 750 µm using pressurized air or water as driving fluid.

1. Recognizing of the problem in literature and technical solution:

Main problem expected to be found in the design of the large piston is the deformation, due to pressure and temperature. The heat coming from the exhaust gases will be the main reason of deformation.

2. Data of the engine:

Table 1. Specifications of the engine.

Description	Value
Configuration	Two-stroke diesel engine cooled by air
Max pressure 'p_{max}'	5 MPa
Temperature in combustion chamber 'T'	900 K
Bore 'D'	300 mm
Rotation speed 'n'	750 rpm
Specific fuel consumption 'g_e'	0.3 kg/kWh
Power 'N_e'	300 kW per one cylinder
Calorific value (gasoline and oil) 'W_d'	42000 kJ/kg
Piston cooling	By oil maximum temperature 500K

III. DESIGNING CRITERIA

1. Cooling System:

Piston engines, and, in particular, internal combustion engines, are often cooled using lubrication oil. This is traditionally achieved by spraying lubrication oil onto the piston, to facilitate cooling in the lower part of the piston crown surface. In big engines this system becomes inefficient due to the huge amount of heat to be transferred.

To correct this problem large amount of oil sprayed is required. This requires additional components such as larger than necessary oil storage tanks, reducing engine's power to weight ratio and increasing manufacturing an operational cost of the engine. Accordingly, heat transfer between a piston and the lubrication oil is not uniform across the engine. This causes thermal gradients and strains within the engine potentially leading to the formation of cracks.

To solve this problem a uniform cooling system is needed. Including a tortuous flow channel in the piston crown, uniform cooling is achieved. This is made to increase the contact surface between the lubrication oil flowing through the cooling chamber and the piston head and also, prolong the contact time period during which the lubrication oil contacts the piston head.

The lubrication oil is injected into the cooling chamber through a series of fluidly coupled channels embedded in a crankshaft and a rod connecting the piston head to the crankshaft. After heat exchange with the piston head in the cooling chamber, the lubrication oil is returned to the crankshaft.

As a result, heat transfer is conducted uniformly in every piston. This can significantly reduce the chance of engine failures caused by thermal gradients and strains within the engine. There are multiple solutions to the description given before [4].

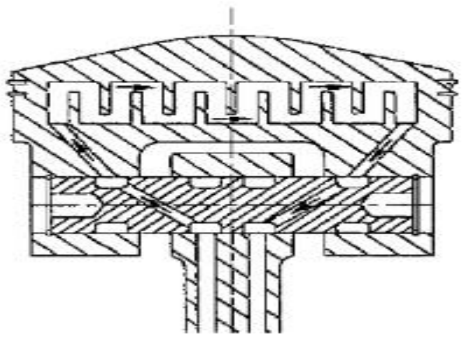

Fig 1. Sealed lubrication.

In Fig. 3.1 it can be seen a first solution. It is a schematic flow diagram of an embedded cooling system used by a piston engine. This lubrication system is sealed. The oil goes in and out through the connecting rod.

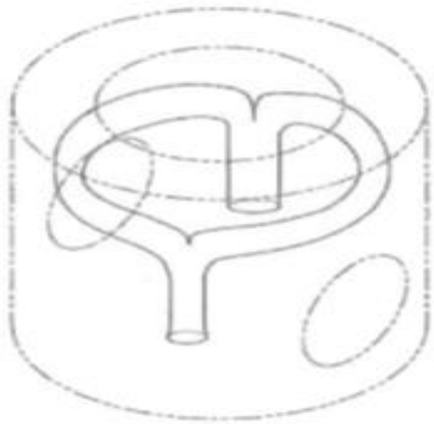

Fig 2. Sealed cooling system surrounding the piston head.

In Fig. 3.2 there is another sealed cooling system. The difference between this one and the one shown in Fig. 3.1 is that this one only goes by the exterior area of the piston crown. It is a good approach but it does not treat the interior part of the piston crown. This could lead to thermal gradients and strains in the inner part of the piston [5].

2. Piston Rings:

Generally, a compression ring and an oil ring are attached as a set of a piston ring to a piston that performs reciprocating motion. The compression ring possesses a function to prevent a phenomenon called blow-by. High-pressure combustion gas flows into the crankcase from the combustion room. On the other hand, the oil ring mainly possesses the function to suppress the excess of lubricant on the inner wall of the cylinder liner. The main function of the piston rings is to seal the combustion chamber from the rest of the engine. There are some considerations that must be done before designing the piston rings. The first piston ring should not be too far back the piston head. This increases the volume of the gap between the piston and the cylinder walls, this increases the secretion of hydrocarbon compounds into the exhaust gases. Number of rings, from which depends on the height of the annular part is related primarily to the speed of the engine and the pressure of the combustion.

At medium speeds, the first ring takes over the 75% of the entire pressure. The choice of the number of rings should be the result of careful analysis, with one hand, depends on to the gas that passes into the crankcase should be the minimum, on the other, the number of rings determines the mass of the piston, engine height and friction losses. The next figure shows some examples of some designs in piston rings andalso, the flowing of the oil while working[6].

a), b) pumping oil through the rings, c), d) scraping and oil flow towards the piston, e) clearance between the piston ring and the piston itself During the movement of the piston towards the

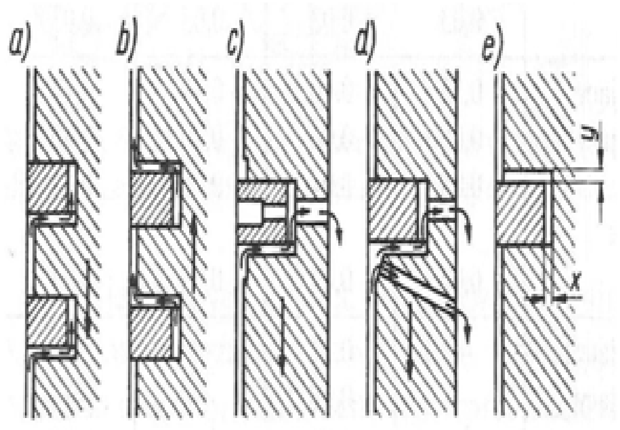

Fig 3. Examples and designs of piston rings.

BDC friction rings occupy the position shown in fig. a. with the craped oil filling the clearance existing between the rings and grooves in the piston. During the movement to the TDC oil moves over rings as fig. 2.3.b. Oil, which thus moves to the side of the TDC, is finally burned in the combustion chamber. Burnt oil is not only an economical issue, but also can significantly increase the emissions of toxic components in the exhaust gases, particularly in the form of hydrocarbons.

In addition, burning oil creates a sludge and carbon deposits in the combustion chamber, which easily lead to SI engines to self-igniting. The intensity of the phenomenon of the oil pump may be decisive to decide the axial clearances. Approximate clearances are shown in the next table [7, 8]

3. Selection of Materials:

Adverse working conditions make the requirements of the materials used in the piston very wide and diverse. Materials used in the piston manufacturing can be divided in the following groups:

- Cast iron (non-alloy and alloy steels)
- Aluminium alloys
- Special steel

Cast iron used in piston is usually perlite structure with separate laminas. When alloyed, more fine-grained structure is obtained and will improve the mechanical properties of the material.

The advantages of cast iron are: good sliding properties, high abrasion resistance, small decrease in strength and hardness in high temperatures, small coefficient of thermal expansion. Disadvantages are: high density and small coefficient of heat conduction. Hardness in cast iron should be in the range 180 – 240 HB and also, should be adapted to the hardness of the rings and cylinder walls. Besides, for uniform pistons with larger speeds light alloys of aluminum are used.

3.1 Advantages in aluminium alloys:

Low density (approximately three times less than cast iron), good thermal conductivity, ease in casting and good machinability. Disadvantages are: mean coefficient of linear expansion (2.5 times greater than cast iron), lower hardness, decrease in strength in high temperatures and finally slightly higher price. Small density of aluminium allows the construction of lightweight pistons, which influences positively in fuel consumption and also reducing the stress and pressure from inertia forces.

Concerning the relative large coefficient of heat conduction attached to aluminium alloys results in lowering the temperature of the piston crown. It is very important especially in spark-ignition engines. Next figure is a comparison between both engines spark-ignition and diesel engines.

To reduce a major drawback in the alloy is preferable to choose the lowest rate of coefficient of expansion, by the addition of Si (up to 20%) this effect is considerably lowered, so consequently, improved. In order to increase resistance to abrasion, piston alloy is heat treated and artificially aged, so that hardness of 120 - 140 HB can be achieved. Aluminium alloys can be divided into the following main groups:

- Copper aluminium alloys Al-Cu
- Eutectic aluminium alloys Al-Si
- Hypereutectic aluminium alloys Al-Si

Al-Cu alloys are characterized by high thermal conductivity, which is the basic advantage; further advantage is slightly higher strength at high temperatures.

One disadvantage is a significant linear coefficient of thermal expansion. Eutectic alloys Al-Si have a lower coefficient of linear expansion and thermal conductivity at the same time. Hypereutectic aluminium alloys Al-Si have the lowest coefficient of linear expansion and the major resistance to abrasion of all aluminium alloys. Al-Si alloys are now widely used. Particularly they are suitable for air-cooled engines, supercharged engines and two-stroke engines. Another benefit of Al-Si alloys is the ease of casting.

Cast steel has a greater strength compared to aluminium alloys which allows performing relatively thin bottoms, which not only allows maintaining a moderate weight piston, but if cooled the bottom reduces the chances of appearing thermal stresses by reducing the temperature gradient. Good resistance to abrasion and small linear coefficient of thermal expansion are also important advantages to cast steel. The unfavourable point to cast steel is the conductivity of the material which is five times less than light alloys.

The primary method of producing pistons is casting. Casting in moulds (shells), used in lightweight alloys, result in a more fine-grained structure of the material and better mechanical properties. In some types of engines forging is used. It evokes positive changes in the structure of the material but requires proper interior shape of the piston. In order to improve the strength properties and hardness of the alloy pistons are applied appropriated machining heat. It has the objective of removing stress after casting of forging and ensuring the stabilization of dimensions

IV. CONCLUSION

This paper isconcluding very higher difficulties arise of piston material selection. Also previous article do not suggest suitable approach to selection of piston material. One the other hand most important things recently use Artificial intelligence are used to classification and optimization of material based on its properties. In this review piston designing tolerance assignment is very important in product design and machining.

The conventional sequentially tolerance allocation suffers from several drawbacks as show for previous article. Therefore, a simultaneous tolerance assignment approach is adopted to overcome these drawbacks. However, the Materials optimization of task is usually difficult to tackle due to the nonlinear, multi-variable and high constrained characteristics.

In trying to solve such constrained optimization problem, penalty function based methods have been the most popular approach. Hence Father Work of this review uses Advance artificial intelligence method to selection of piston design materials.

REFRENCES

[1] Zare, S.H.; Tavakolpour-Saleh, A.R.; Omidvar, A.: From Beale number to pole placement design of a free piston Stirling engine. Arch. Mech. Eng. 64, 499–518 (2017). CrossRefGoogle Scholar.
[2] Jokar, H.; Tavakolpour-Saleh, A.: A novel solar-powered active low temperature differential Stirling pump. Renew. Energy 81, 319–337 (2015) CrossRefGoogle Scholar.
[3] Ahmadi, M.H.; Ahmadi, A.A.; Pourfayaz, F.: Thermal models for analysis of performance of Stirling engine: a review. Renew. Sustain. Energy Rev. 68, 168–184 (2016) CrossRefGoogle Scholar.
[4] Tavakolpour, A.R.; Zomorodian, A.; Golneshan, A.A.: Simulation, construction and testing of a two-cylinder solar Stirling engine powered by a flat-plate solar collector without regenerator. Renew. Energy 33, 77–87 (2008) CrossRefGoogle Scholar
[5] Zare, Sh; Tavakolpour-Saleh, A.R.: Frequency-based design of a free piston Stirling engine using genetic algorithm. Energy 109, 466–480 (2016) CrossRefGoogle Scholar.
[6] Zare, S.H.; Shourangiz-Haghighi, A.R.; Tavakolpour-Saleh, A.R.: Higher order modeling of a free-piston Stirling engine: analysis, and experiment. Int. J. Energy Environ. Eng. 9, 273–293 (2018). CrossRefGoogle Scholar.
[7] Der Minassians, A.: Stirling engines for low-temperature solar-thermal-electric power generation. ProQuest, Ann Arbor (2007)Google Scholar.
[8] Tavakolpour-Saleh, A.R.; Zare, S.H.; Bahreman, H.: A novel active free piston Stirling engine: modeling, development, and experiment. Appl. Energy 199, 400–415 (2017)CrossRefGoogle Scholar.
[9] Tavakolpour-Saleh, A.R.; Zare, S.H.; Badjian, H.: Multi-objective optimization of Stirling heat engine using gray wolf optimization algorithm. Int. J. Eng. (IJE) Trans. C Asp. 30(6), 150–160 (2017)Google Scholar.
[10] Solmaz, H.; Karabulut, H.: Performance comparison of a novel configuration of beta-type Stirling engines with rhombic drive engine. Energy Convers. Manag. 78, 627–633 (2014)CrossRefGoogle Scholar.
[11] Zare, S.H.; Tavakolpour-Saleh, A.R.: Nonlinear dynamic analysis of solar free piston hot-air engine. Modares Mech. Eng. 15(9), 223–234 (2015)Google Scholar.
[12] Riofrio, J.A.; Al-Dakkan, K.; Hofacker, M.E.; Barth, E.J.: Control-based design of free-piston Stirling engines. Am. Control Confer. 2008, 1533–1538 (2008) Google Scholar.