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Research Article

Waste Heat Recovery of IC Engine using Stirling Engine

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Abstract

Now-a-days IC engines are widely used. Out of the total heat supplied to the I.C engine in the form of fuel 30-40% heat is converted into useful work and remaining 60-70 % as a part of waste heat as friction, exhausts gas and engine cooling system. Through the exhaust of engine 30-40 % of heat is lost to the environment, resulting in to entropy rise and serious environmental pollution, so it is required to utilize waste heat into useful work. Waste heat is the heat which is generated in a process by a fuel consumption and released into the environment, though it can be used for economical and some useful purpose. Some power of IC engine is used to run alternator which reduces the mileage. The Stirling engine is used to remove the electrical load from the IC engine and thereby increasing the fuel efficiency of the engine. It works on the principle of temperature difference. This paper investigates recovery of the exhaust waste heat using a Stirling engine with internal combustion engine for the automobiles to increase the fuel economy, the useful power, and the environment safety. A Stirling engine requires only an external heat source as wasted heat for its operation. Because the exhaust gas temperature may reach 200 to 700°C, Stirling engine will work effectively.

Keywords: *Fuel efficiency, IC engine, Stirling engine, Waste heat recovery*

1. Introduction

IC engine is the device which converts the chemical energy of fuel into heat energy and again the heat energy into mechanical work. Out of the total heat supplied to the IC engine in the form of fuel approximately 30 to 40% is converted into useful mechanical work and the remaining heat is exhausted in to environment. As the economy increases, energy demand also increases. This results in the more usages of fossil fuels which causes the emission of harmful gases. Large amount of heat is expelled in the atmosphere from IC engine without utilizing for any purpose (Pradip *et al*. 2015). The exhaust gas contains many pollutants like carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NO_x) and particulate matter (PM). Because of these harmful gases, the environment gets polluted and effects like Green-house effect and global warming are arising. Because of hot exhaust gas the temperature of surrounding is also increased. Due to this serious problem scientist and engineers have done lots of successful research to improve engine thermal efficiency. Many researchers came to know that waste heat recovery from IC engine is the key solution to decrease fuel consumption without increasing emission (J. S. Jadhao *et al*. 2013). Stirling engine is one of the best solutions to recover the waste heat of IC engine. Stirling engine is the engine that converts the heat energy into mechanical work with high efficiency. It works on temperature difference. In automotive engine IC engine are used to power the alternator which in turn charges the battery. The engine consumes more fuel due to the additional electrical load. Stirling engine is used to reduce the consumption (S. Prakash *et al*. 2011).

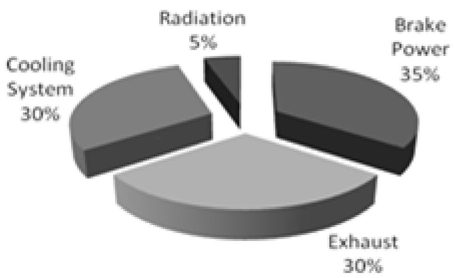

Fig.1 Fuel Energy balance in IC engine

2. Stirling Engine

The Stirling engine was invented and patented by Robert Stirling in 1816. It followed earlier attempts at making an air engine but was probably the first to be put to practical use when in 1818 an engine built by Stirling was employed pumping water in a quarry. A Stirling engine is a heat engine operating by cyclic compression and expansion of air or other gas, the

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working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work. The engine resembles a steam engine in having all heat transfer flowing through the engine wall. This is traditionally designated an external combustion engine in contrast with an internal combustion engine where the heat is put in by combustion of fuel within the body of the working fluid. Unlike the steam engine's usage of water as the working fluid in both its liquid and gaseous phases, the Stirling engine encloses a fixed quantity of permanently gaseous fluid such as air or helium. Typical of heat engines, the general cycle consists of compressing cool gas, heating the gas, expanding the hot gas, and finally cooling the gas before repeating the cycle (Prof. Alpesh V. Mehta *et al.* 2012).

3. Stirling engine Principle

It converts thermal energy into mechanical energy by following Stirling cycle.

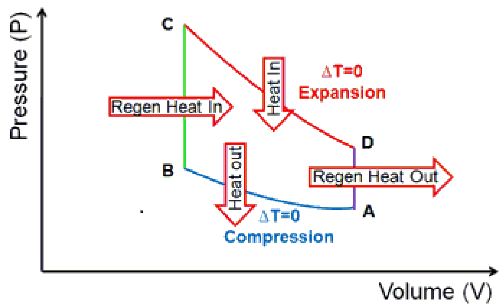

Fig.2 Stirling Cycle PV diagram

1) Isothermal compression- Work W1-2 is done on the working fluid, while an equal amount of heat Q1-2 is rejected by the system to the cooling source. The working fluid cools and contracts at constant temperature T_C.
2) Isochoric heat addition- Heat Q2-3 is absorbed by the working fluid and temperature is raised from TC to T_H. No work done.
3) Isothermal expansion- Work W3-4 is done by the working fluid while an equal amount of heat Q3-4 is added to the system from the heating source. The working fluid heats and expands at constant temperature T_H.
4) Isochoric (constant volume) heat removal- Heat Q4-1 is rejected by the working fluid temperature decreases from T_C to T_H. No work done.

4. Stirling engine Operation

Stirling engine works on closed cycle. It contains fixed mass of gas which is called 'working fluid'. It may be air, Hydrogen (H) or Helium (He). The engine is sealed and no gas enters or leaves the engine. The Stirling engine operates on four main process – cooling, compression, heating and expansion. Power piston has compressed the gas; the displacer piston has moved so that most of the gas is adjacent to the hot heat exchanger. The heated gas increases in pressure and pushes the power piston to the farthest limit of the power stroke. The displacer piston now moves, shunting the gas to the cold end of the cylinder. The cooled gas is now compressed by the flywheel momentum. This takes less energy, since when it is cooled its pressure dropped.

5. Types of Stirling engine

5.1 Alpha type 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. The generator is illustrated by the chamber containing the hatch lines.
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.

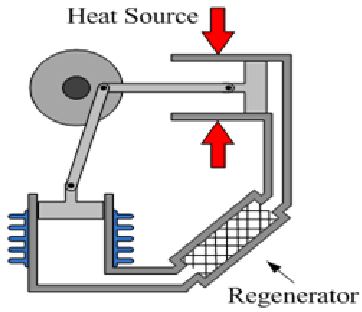

Fig.3 Alpha Stirling Engine

5.2 Beta type Stirling engine

A beta Stirling has a single power piston arranged within the same cylinder on the same shaft as a displacer piston. When it is pushed to the cold end of the cylinder it contracts and the momentum of the machine, usually enhanced by a flywheel, pushes the power piston the other way to compress the gas. Unlike the alpha type, the beta type avoids the technical problems of hot moving seals.

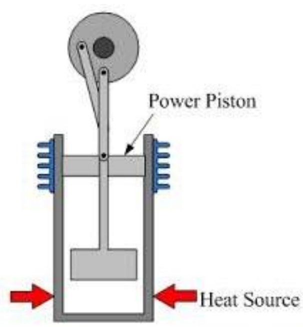

Fig. 4 Beta Stirling engine

5.3 Gamma type Stirling engine

A gamma Stirling is simply a beta Stirling in which the power piston is 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 Stirling engines.

Furthermore, during the expansion process some of the expansion must take place in the compression space leading to reduction of specific power. Gamma engines are therefore used when the advantages of having separate cylinders outweigh the specific power disadvantage.

The advantage of this design is that it is mechanically simpler because of the convenience of two cylinders in which only the piston has to be sealed.

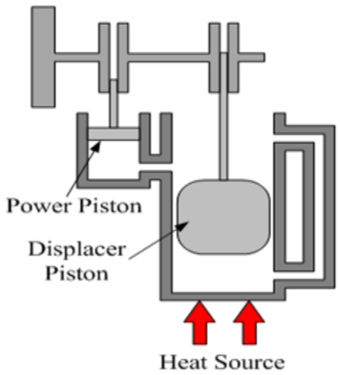

Fig.5 Gamma Stirling engine

6. Alternator

An alternator is an electromechanical device which converts mechanical energy into electrical energy in the form of alternating current. Very large automotive alternators used on buses, heavy equipment or emergency vehicles may produce 300 amperes. Very old automobiles with minimal lighting and electronic devices may have only a 30 amperes alternator. Typical passenger car and light truck alternators are rated around 50-70 A, though higher ratings are becoming more common, especially as there is more load on the vehicle's electrical system with, for example, the introduction of air conditioning and electric power steering systems.

6.1 Power consumption of alternator

Alternator has to charge a 50A and 12 V batteries, so the power is consumption is 600 Watts. We need minimum of 12 hours to charge 12 Volt Lead Acid batteries. Therefore, the total power consumption is 7200 Watts. This amount of power is consumed from engine and it decreases the mileage of the vehicle. The alternator's rotor should be rotated at 2000 RPM to get 60 A of current.

6.2 Charging battery using Stirling engine

In this case, Stirling engine is used to rotate the rotor of the alternator. By doing this, the electrical load on the engine can be nil. The material for cylinder and piston of the Stirling engine are selected in such way that the specific weight of the Stirling engine is low. Copper is chosen for the construction of cylinder since it has the high thermal conductivity and low density compared to the other materials.

Table 1 Thermal conductivity and density of metal

Metal or Alloy	Density (kg/m^3)	Thermal conductivity (W/m.k)
Aluminium	2560-2640	250
Aluminium bronze (3-10% Al)	7700-8700	346.1
Copper	8960	401

7. Implementation

The basic requirement to run the Stirling engine is the temperature difference. The temperature difference can be obtained from RADIATOR. The radiator has two ends through which the coolant passes removing the heat from the engine. The heat is transferred to the air present inside the cylinder by conduction and convection. The hot end of the Radiator is in contact with the one end of the Stirling engine and the cold end of the radiator is connected to the other end of the Stirling engine. It is found that the temperature difference obtained between the radiator ends is approximately equal to 70^{O}C.

$$W = R\,(T_h - T_c)\ln(V_b/V_a) \qquad (1)$$

T_h - hot side temperature;
TC - cold side temperature;
$T_h - T_c = 70^{O}C$
R - Universal gas constant =8.314 J/K.mol;
V_b/V_a - volumetric ratio =5 (Assume).

With 70^{O}C temperature difference the power output from the Stirling engine is 950 Watts (assuming the volume ratio to be 5). The alternator consumes 600 Watts power to charge the 12-volt battery.

So,

$W = R\,(T_h - T_c)\ln(V_b/V_a)$
$=8.314*70*\ln(5)$
$W = 936.66\text{Watt} \approx 950$ Watt

So Stirling engine can be certainly used to run the alternator's rotor and produce current. This type is more advantageous than the conventional method because, Stirling runs at constant speed not like Internal Combustion engine. Since the Stirling has low torque, initially it has to be rotated by clutching mechanism. If it is started the Stirling engine can run at constant speed till the temperature difference exists. The ends of a radiator are used to run the Stirling engine. As the radiator removes the heat from the engine; the hot end has high temperature and since heat carried by the coolant is radiated out the other side of radiator has low temperature. This temperature difference is used to run the Stirling engine at the required of the alternator. The Stirling engine's shaft is coupled with the rotor of the alternator. The alternator produces power since the rotor cuts the magnetic field present inside the alternator.

Conclusions

The Waste heat from IC engine is utilized and power is produced by Stirling engine.

1. The power which is recovered by Stirling engine can be used to charge vehicle's batteries or to operate the mechanical auxiliary such as oil pump, water pump, A/C compressor.
2. Environment Pollution like Green House effect and Global Warming are reduced.
3. As all the automobile industries working for increase in mileage, this idea will be helpful to do that. Thus by using the Stirling engine to run the alternator, the fuel consumption of an IC engine can be decreased and thereby more kilometers can be travelled per litre than the existing numbers.

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