Exhaust Waste Heat Recovery System

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Abstract. The current worldwide trend of rapid economy development and increasing energy demand in transportation sector are one of many segments that is responsible for growing share of fossil fuel usage. Supply and demand for fuel is accelerating prices and eventually will affect availability. The selected contemporary paper will address on how a prototype stirling engine capable of harnessing waste heat spilling out of typical engine exhaust and to fight against the tyranny of inefficiency. Stirling engine systems are fuel flexible with respect to source of thermal energy and unprocessed waste heat that resulting in entropy rise can be harvested to power ancillaries and increase overall efficiency. The preliminary prototype design and methodology follows process, heat to mechanical energy and latter to electrical energy. Experimental verification of analytical data was carried out and presented here. Shortcomings of these methods are highlighted and an alternative approach to solve particulars suggested.

Keywords:Fossil Fuel,Waste Heat, Stirling Engine, Harnessing,Efficiency, Electrical Energy

INTRODUCTION

Any physical activity in this world whether by human beings or by nature is caused due to flow of energy in one form or the other. Energy is most basic infrastructure input required for economic growth and development of a country. Also, energy has been life blood for continual progress of human civilization. Thus, with an increase in living standard of human beings, energy consumption also accelerated. Per capita consumption of a country is an index of standard of living [2].

In an era of expensive fuel and concern, automobile has come under increasing scrutiny with consumers looking for ways to extend mileage. Also, the automotive world is on the verge of a major shift in paradigm, essaying a revival of end of the 19th century where electric vehicles were rule rather than exception.

Oil prices shot up four folds causing severe energy crisis the world over. This result in spiraling price rise of various commercial energy sources leading to global inflation. It's hardly a revolutionary number, until being considered that world consumes 85 billion barrels of oil a day [2]. In fact, reducing global impacts of conventional energy resources and meeting the growing energy demand had motivated considerable research attention in a wide range of engineering application of energy.In general within an automobile, two-thirds of the fuel used is emitted as waste heat. In total, about 30% of the energy supplied is converted into useful work; about 30% is lost as exhaust heat and some energy is lost in friction, compression and direct rejection. The rest of the energy about 30%, has to be removed by cooling system [1]. Less attention has been put until recently on recovery of waste heat in vehicle. The use of turbo-charger is also a way of recovering a portion of exhaust gas energy, although the deployment of such device may be problematic, especially for petrol engines [1].BMW researchers in Munich, Germany, have utilized steam technology to harness the wasted heat energy in the exhaust system of their cars [3].

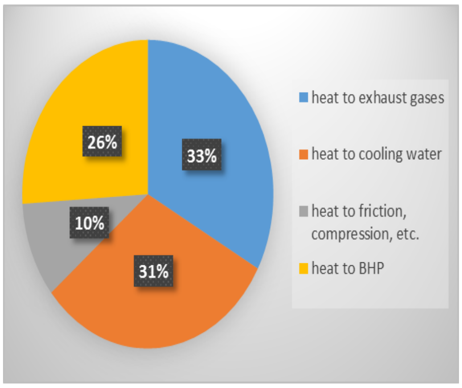

Fig.1 Heat balance for a typical engine

Stirling engines could be utilized as possible alternative viable approach to recover waste heat.A stirling engine is a heating engine operating by cyclic compression and expansion of air or other gas. However, stirling engine unique feature that, if ideal stirling thermosynamic cycle were practically realizable the efficiency of a frictionless stirling engine would be the same as that of a Carnot cycle engine,i.e., the maximum theoretically attainable in any heat engine [1,3].

Design of Experiment

Fig.2 steel wool displacer inside a can serving as a pressure vessel

A prototype, beta configuration stirling engine had been assembled which constitutes a single power piston arranged within the same cylinder on the same shaft [5].The displacer piston is a loose fit and does not extract any power from the expanding gas but only serves to shuttle the working gas from the hot region to the cold region. When the working gas is pushed to the hot end of the cylinder it expands and pushes the power 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.

Displacer. The displacer is made from steel wire wool wrapped around a piece of steel wire. Displacer needs to fall freely under it's own weight inside of the pressure vessel. The diameter of pressure vessel is 65 mm with a height of 90 mm, Taking radial clearance of 2mm, so the diameter of displacer is approximately calculated as 60mm and height is 65mm.

Stroke = (height of cylinder-thickness of displacer)-(2×clearance).(1)

Stroke =15mm, calculated from Eq 1.

Crank radius = $\frac{\text{stroke}}{2}$. (2)

Crank radius, calculated 7.5mm, calculated from Eq 2.

Power piston and cylinder. Power piston is the most important part of engine. It produces power stroke from the expansion of air in power piston. Power piston and cylinder must have very low friction. From empirical relation power piston expansion volume should be around 1/25 times swept volume of displacer cylinder [1].

Swept volume of displacer cylinder = $\frac{\pi}{4}\times 65\times 65\times 15=49774.6\ mm^3$.(3)

Power piston expansion volume = $\frac{49774.6}{25}=1990.984mm^3$.(4)

Diameter of power piston cylinder = $\sqrt{\frac{1990.984\times 4}{\pi\times 15}}$=13 mm. (5)

Crankshaft. It converts reciprocating motion into rotary motion and also supports flywheel. With 2mm diameter of wire, 90mm length and 90^o phase angle.

Flywheel. Made up of plastic with 120 mm diameter, 1 mm thickness.

(a)

(b)

(c)

Fig.3 (a) Crank Shaft, (b) Fly Wheel, (c) Final assembly of prototype stirling.

Experimental Set-up and Simulation

The expansion side of stirling engine model is thermally coupled to heat source and compression side of stirling device is placed in environment.

Pressure observed in the device is 829.69 Pa and speed of 13 rpm. Hencea force of 0.4233 Nis obtained on the piston.

Therefore the following are outputs are obtained from the model (Eq 6, Eq 7)-

Torque = force × radius = 6.5×10^{-3}N-m. (6)

Power = $\frac{2\pi\times13\times6.5}{60\times1000}$=0.01W. (7)

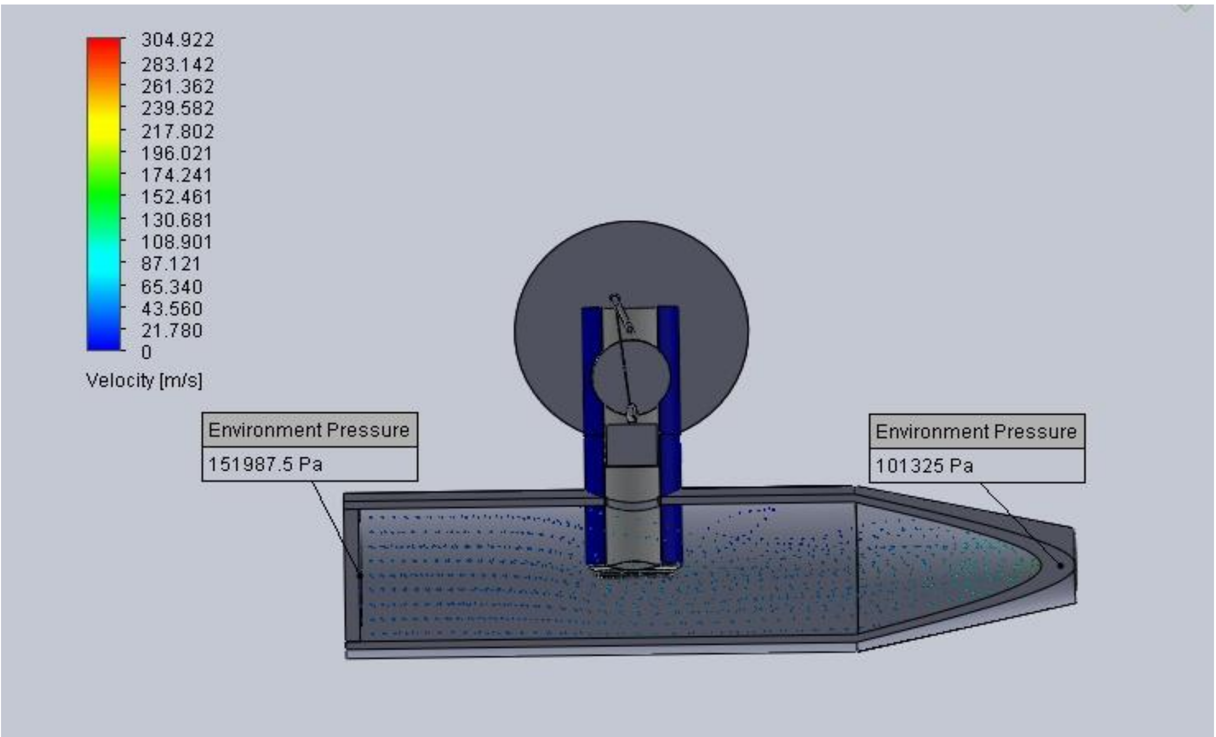

Fig.4 This shows an attempt to install the device in exhaust manifold and simulation result particularly in 2-wheeler, made in Solid Works 2013 SP®.

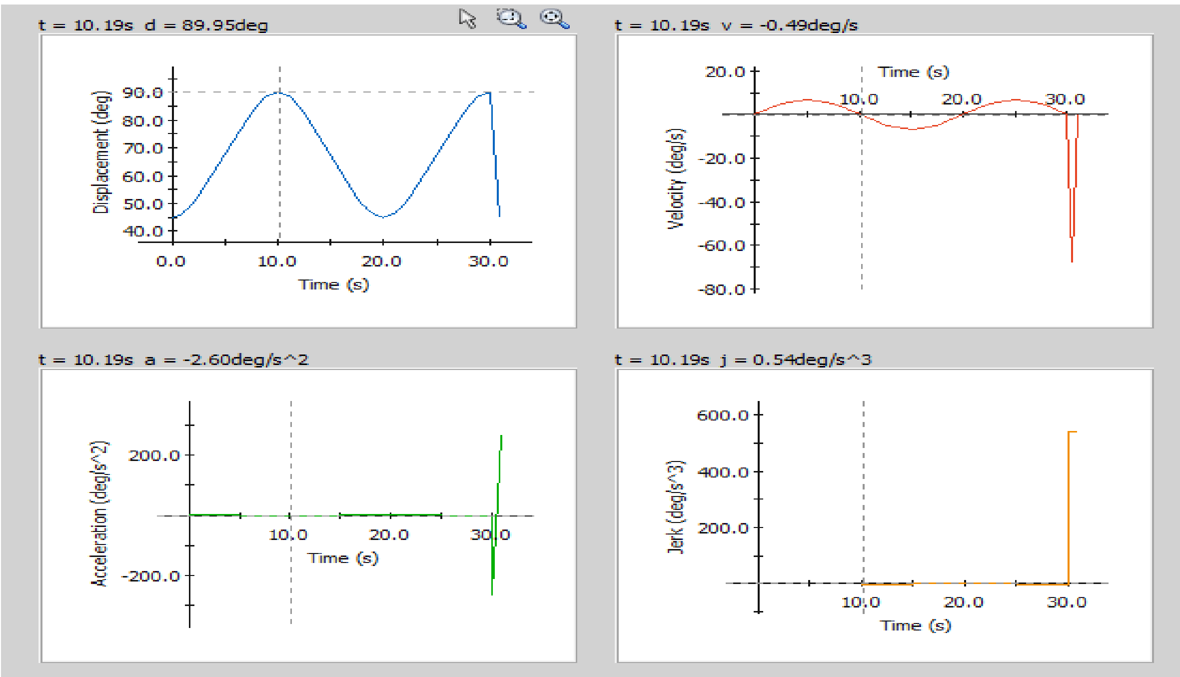

Fig.5This shows motion of prototype stirling model under simulating condition, i.e., variation of displacement, velocity, acceleration, jerk with respect to time.

RESULT & DISCUSSION

The above generated analytical data for model was 0.01 W, Therefore by Similitude process for generating prototype power of 1 KW, working fluid as air and implementing Froude's Model law [7], scale ratio Lr =

26.85, empirical relation-

$$\frac{\omega_p}{\omega_m} = \sqrt{Lr} \Rightarrow \omega_p = 67.362 \text{ rpm.} \quad (8)$$

$$\frac{P_p}{P_m} = Lr \Rightarrow P_p = 22277.17 \text{ Pa.} \quad (9)$$

$$\frac{Vol_p}{Vol_m} = Lr^3 \Rightarrow Vol_p = 963475440 \text{ mm}^3. \quad (10)$$

$$\frac{Power_p}{Power_m} = Lr^{3.5} \Rightarrow Power_p = 1 \text{ KW.} \quad (11)$$

Summary

The above analytical data of Similitude, scaled 26.85 is capable of generating prototype power of 1 KW. But depending on the difference between simulated and user defined engine pressure more improvement can be observed from the original simulation. The simulated results provides a satisfactory prediction of engine's performance as compared to the experimental data by scaling. i.e. if the supplied heat is increased, more work output can be obtained from the experimental model.

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