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Waste Heat Recovery System by Using Thermoelectric Modules from Internal Combustion Engines

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Abstract— ***A number of irreversible processes in the engine limit its capability to achieve a highly balanced efficiency. The rapid expansion of gases inside the cylinder produces high temperature differences, turbulent fluid motions and large heat transfers from the fluid to the piston crown and cylinder walls. These rapid successions of events happening in the cylinder create expanding exhaust gases with pressures that exceed the atmospheric level, and they must be released. By doing so, the heated gases produced from the combustion process can be easily channeled through the exhaust valve and manifold. The large amount of energy from the stream of exhausted gases could potentially be used for waste heat energy recovery to generate power. Various methods to harness the waste heat to produce power effectively had ended up in vain. This paper proposes and implements a thermoelectric waste heat energy recovery system for internal combustion engine automobiles, including gasoline vehicles and hybrid electric vehicles. The key is to directly convert the surface heat energy from automotive waste heat to electrical energy using a thermoelectric generator (TEG). which is then regulated by a DC– DC Cuk converter to charge a battery using maximum power point tracking. Hence, the electrical power stored in the battery can be maximized. The experimental results demonstrate that the proposed system can work well under different working conditions, and is promising for automotive industry***.

Keywords: - TEG, piston crown, Thermoelectric Modules, Combustion Engines, irreversible processes

I. INTRODUCTION

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. Even a highly efficient combustion engine converts only about one-third of the energy in the fuel into mechanical power serving to actually drive the automobile. The rest is lost through heat discharged into the surroundings or, quite simply, leaves the vehicle as “waste heat”.

The current research is focusing on a technology, which is able to convert the thermal energy (THERMO ELECTRIC GENERATOR) contained in the exhaust gas directly into electric power. Here TEG is mounted on the rectangular copper box to improve TEG’s efficiency. A thermoelectric power generator is a solid state device that provides direct energy conversion from thermal energy (heat) due to a temperature gradient into electrical energy based on “Seebeck effect”. The thermoelectric power cycle, with charge carriers (electrons) serving as the working fluid, follows the fundamental laws of thermodynamics and intimately resembles the power cycle of a conventional heat engine. The TEG specifications is shown in table 1.

TEMPERATURE DIFFERENCE(℃)	VOLTAGE (V)	CURRENT (mA)
20	0.97	225
40	1.8	368
60	2.4	469
80	3.6	558
100	4.8	669

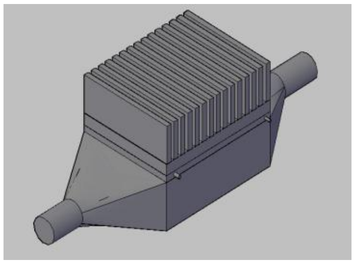
Table 1: TEG specifications

II. METHODOLOGY

The vehicle is started and the acceleration is to be given, so that the amount of heat leaving the exhaust will be increased. Due to this heat, the surface of the exhaust pipe and the copper box will be heated to very high temperatures. These hot surfaces will try to liberate the heat to the atmosphere, which acts as a Heat Source. Since the atmospheric temperature is less than that of the copper box surface, a temperature difference is created and hence the surface tries to attain the equilibrium state through the heat transformation process. But this will take much longer time.

Hence in order to increase the rate of heat transfer the Thermal Grease is used. The Thermal Grease is coated on the hot surface of the copper box and also in the inner surface of the fins which are present in the upper part. The fins are also used to increase the heat transfer rate. As the vehicle moves, the air flow will take place between the fins and it acts as the sink.

As the surface of the copper box gets more and more heated the heat transfer rate will increase due to the increase in the temperature difference. The module is placed between the Heat Source (Hot Copper box Surface) and the Heat Sink (atmosphere) and the fins are placed above the module. The module is made of semiconducting materials. Hence by the principle of See-beck Effect, the temperature difference can be directly converted into voltage by using some thermoelectric materials. Based on this effect, when the surface heat of the copper box is passed on to the atmosphere, the electrons and holes of the thermoelectric semiconductors will try to move towards the junction and make the flow of electric current to be possible. The voltage developed due to this effect can be increased by using some Booster circuit like DC-DC Cuk Converter. This will step up the voltage generated to some nominal value. So that we can get the sufficient amount of voltage. For this converter the general formula used to measure the approximate voltage for the given temperature is T=V/10mV. Hence this voltage can be connected to some battery and stored, or else it can be given directly to some electric appliances which uses DC. If we need AC voltage, it can be converted using the rectifier. The voltage generated can be increased by placing more number of modules and connecting them with one another to meet the demand of the required voltage. This voltage can then be supplied to the suitable electrical appliances.



ENGINE SPECIFICATION

Bore Diameter	:	46mm
Stroke Length	:	42mm
Engine Displacement	:	69.9cc
Fuel type	:	Petrol
No of cylinder	:	1

Teg Specification

Material	: Bismuth Telluride Pure	Length	: 40mm
Breadth	: 40mm	Thickness	: 3.6mm
Electrical conductivity	: $1.1 \times 10^5 \Omega^{-1} m^{-1}$	Thermal conductivity	: 1.20 W/ mk
Seebeck co-efficient	: 287 $\mu v / k$		

Fin Specification:

Material	: Aluminium	Base length	: 7mm
Fin length	: 77mm	Fin width	: 30mm
Fin thickness	: 0.562mm	Thermal conductivity	: 236 W/mK

Copper Box Specification**:**

Plate thickness	: 1.6mm	Length	: 120mm
Breadth	: 100m	Height	: 50mm

Experimental Result @ 800RPM

Copper box Inlet Temperature (exhaust manifold) = 70℃
Copper box Outlet Temperature (Silencer inlet) = 44℃
Copper box Surface temperature (TEG hot side) = 75℃
TEG cold side temperature = 56 ℃
Temperature difference between hot and cold side of the TE = 19 ℃
Fin Base temperature = 60 ℃
Fin Tip temperature = 50 ℃

VOLTAGE GENERATED = 4.57 v (Without Booster circuit)

FIN CALCULATION

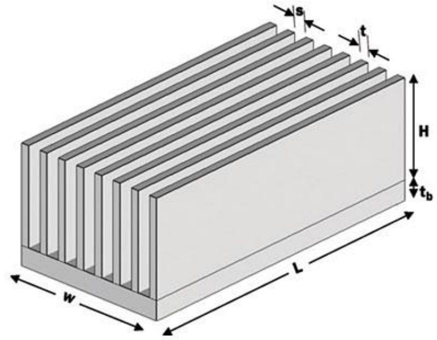


Fig 3 - Fin Dimensions

Width (W) = 0.03m
Thickness (t) = 0.562×10^{-3} m
Wall Temperature (Tw) = 56℃
Fluid Temperature (T∞) = 30℃
Film temperature (Tf) = (Tw + T∞) / 2 = (56 +30) / 2 and Tf = 43℃

Heat Transfer Co-efficient: Properties of Air @43℃

Density (ρ) = 1.1175 kg/ m^3
Absolute viscosity (μ) = 19.267×10^{-6} Ns/m^3
Kinematic viscosity (ϑ) = 17.527×10^{-6} m^2/s
Prandtl number (Pr) = 0.6987
Specific Heat (Cp) = 1005 J/kg K
Thermal Conductivity (K) = 0.02777 W/Mk
Grashof Number (Gr): Gr = ($L^3 \cdot g \cdot \rho^2 \cdot \beta \cdot$ (Tw - T∞)) / μ^2 = ($0.03^2 \times 9.81 \times 1.1175^{\wedge}2 \times 0.00316 \times 26$) / (19.267×10^{-6})^2 and Gr = 73208.258
Rayleigh Number (Ra): Ra = Gr.Pr = 73208.258×0.6987 Ra = 51150.61 < 10^9

∴ *Laminar Flow.*

Nusselt Number (Nu):

$$Nu = \left[0.825 + \frac{0.387\,(Gr\,Pr)^{0.167}}{\left[1+\left(\frac{0.492}{Pr}\right)^{0.5625}\right]^{0.296}}\right]^2 = \left[0.825 + \frac{0.387\,(51150.61)^{0.167}}{\left[1+\left(\frac{0.492}{0.6987}\right)^{0.5625}\right]^{0.296}}\right]^2$$

= 7.878

Also, $Nu = \frac{hL}{K}$ $7.878 = \frac{h \times 0.03}{0.02777}$ h = 7.292 W/m^{2}k

Heat Transfer co-efficient = 7.292 W/m^{2}k

Heat Transfer Rate (Q)

$q = [KAn(Tw - T\infty)]\ \frac{X1}{X2}$ A = w × t = $0.007 \times 0.562 \times 10^{-3}$ A = 4.3274×10^{-5} m^2

$n = \left(\frac{2h}{Kt}\right)^5 = \left(\frac{2\times 7.292}{236 \times 0.562 \times 10^{-6}}\right)^5$ n = 109.96 $X_1 = sinh\,(nl) + \left(\frac{h}{nk}\right)\cosh(nl)$ = $\sinh(109.96 \times 0.03) + \left(\frac{7.292}{109.96\times 236}\right)\cosh(109.96 \times 0.03)$ X_1 = 13.54 $X_2 = \cosh(nl) + \left(\frac{h}{nk}\right) sinh\,(nl)$ $= \cosh(109.96 \times 0.03) + \left(\frac{7.292}{109.96\times 236}\right)\sinh(109.96 \times 0.03)$ X_2 = 13.579

q = $236 \times 4.3274 \times 10^{-5} \times 109.96 \times (56 - 30) \times \frac{13.54}{13.579}$ **q = 29.114 watts** *for "n" number on fin, the heat transfer rate*

Q = nq = 30×29.114 Q = 873.42 watts.

EFFICIENCY OF THE FIN

Fin length, L = 0.03m
Fin thickness, t = 0.562×10^{-3}m
Fin base length, r_1 = 0.007m
r_2 = 0.037m

$$\text{Efficiency, } \eta = \frac{tanh\left[mL\sqrt{\left(\frac{1+\frac{r_2}{r_1}}{2}\right)}\right]}{\left[mL\sqrt{\left(\frac{1+\frac{r_2}{r_1}}{2}\right)}\right]}$$

m = $\sqrt{(2h/kt)}$ m = $\sqrt{\left(\frac{2 \times 7.292}{236 \times 0.562 \times 10^{-3}}\right)}$

m = 10.49 Efficiency, η = $\dfrac{\tanh\left[10.49 \times 0.03 \sqrt{\left(\frac{1+\frac{0.037}{0.007}}{2}\right)}\right]}{\left[10.49 \times 0.03 \sqrt{\left(\frac{1+\frac{0.037}{0.007}}{2}\right)}\right]}$

Efficiency, η = 90.77%

CALCULATION FOR THERMOELECTRIC GENERATOR

TEG hot side temperature (T_h) = 348 K TEG cold side temperature (T_c) = 329 K

Efficiency of the TEG, $\eta = \frac{\Delta T}{T_h} \cdot \frac{\sqrt{ZT+1}-1}{\sqrt{ZT+1}+{T_c}/{T_h}}$ Dimensionless Figure of merit, ZT = $\frac{\sigma \propto^2}{K} T$

$= \frac{1.1 \times 10^5 \times (287 \times 10^{-6})^2 \times 338}{1.02}$ ZT = 2.55 $= \frac{\Delta T}{T_h} \cdot \frac{\sqrt{ZT+1}-1}{\sqrt{ZT+1}+{T_c}/{T_h}}$ $= \frac{19}{348} \frac{\sqrt{2.56+1}-1}{\sqrt{2.56+1}+0.7454}$ η = 1.72 %

VOLAGE GENERATED: According to See beck Effect

V = $\propto \Delta T$ = 287 $\times 10^{-6} \times 19$ V = 0.00543 v

In a single TEG, 256 thermoelectric couples (16 $\times$ 16) are connected in series known as TEG module.

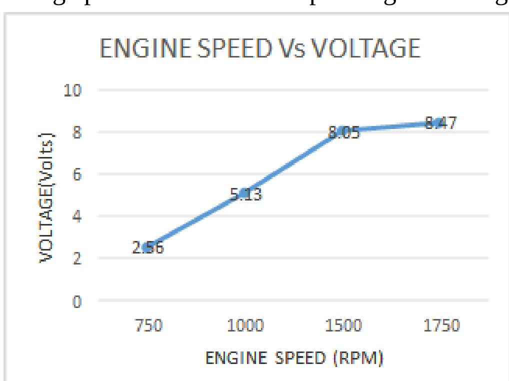
So that voltage generated for single TEG, V = 256 $\times$ 0.00543 V = 1.39v

Temperature Difference (K)	Theoretical voltage (v)	Experimental voltage (v)
19	1.39	1.14

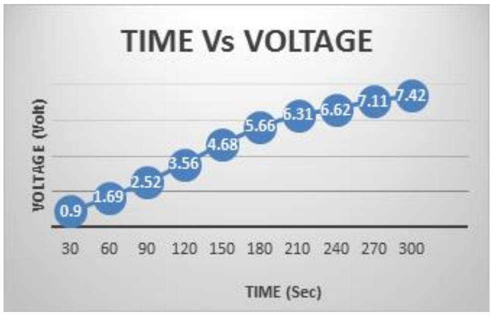
EXPERIMENTAL RESULTS

ENGINE SPEED (RPM)	**VOLTAGE (Volts)**
757	2.56
1000	5.13
1500	8.05
1750	8.47

Table : Voltage produced with corresponding to the engine speed



TIME (SEC)	**VOLTAGE (VOLTS)**
30	0.9
60	1.69
90	2.52
120	3.56
150	4.68
180	5.66
210	6.31
240	6.62
270	7.11
300	7.42



Figue : Comparison Chart

III. CONCLUSION

The key is to directly convert the surface heat energy from automotive waste heat to electrical energy using a thermoelectric generator (TEG). which is then regulated by a DC– DC Cuk converter to charge a battery using maximum power point tracking. Hence, the electrical power stored in the battery can be maximized. The experimental results demonstrate that the proposed system can work well under different working conditions, and is promising for automotive industry

REFERENCES

[1] Birkholz E, Grob U, Stohrer and Voss K. (1988) ‘Conversion of waste exhaust heat in automobiles using FeSi2 thermo-elements”, Proceedings of 7th International Conference on Thermoelectric energy conversion, University of Texas, March 16-18, 1988, pp.124-128. (Conference)

[2] Jumade S R, Khond V W, (2012), "A Survey on Waste Heat Recovery from Internal Combustion Engine Using Thermoelectric Technology",
International Journal of Engineering Research & Technology | Vol. 1 | Issue 10 | December- 2012| ISSN: 2278-0181. (Journal)

[3] Baskar P, Seralathan S, Dipin D, Thangavel S, Norman Clifford Francis I J and Arnold C. (2014), "Experimental Analysis of Thermoelectric Waste Heat Recovery System Retrofitted to Two Stroke Petrol Engine",

[4] International Journal of Advanced Mechanical Engineering - ISSN 2250-3234 | Volume 4 | pp. 9-14. (Journal) Basel I. Ismail, Wael H Ahmed (2009) Thermoelectric Power Generation Using Waste-Heat Energy as an Alternative Green Technology, Recent Patents on Electrical Engineering, 2, 27-39.