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"Experimental Investigation on Thermoelectric Generator used for Exhaust Gas of a Four Stroke S.I. Engine"

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Abstract - *In the present scenario, energy crisis and thermal energy management are the critical topics. A great deal of automotive industry's research and development efforts is focused on improving the overall efficiency of the vehicle. A major part (around 20%-30%) of the heat supplied in an internal combustion engine is not converted into useful energy, but dumped into the atmosphere as waste heat so it becomes necessary to recover this waste heat. The useful energy which drives the engine is also used to run generator, as a result of which the efficiency of such an engine is very low.*

To improve the engine efficiency various methods are developed to utilize waste heat from the exhaust gas. One of the promising technologies that is used for this purpose is thermoelectric generator. Thermoelectric generators are solid state devices that are used to convert thermal energy from a temperature gradient to electrical energy. This project involves conceptual model of power generation from the exhaust gas of a four stroke four cylinder S.I. engine using a single Bi_2Te_3 thermoelectric generator at different gears and at different cylinder cutoff. The output power from each cylinder of the engine was investigated using Morse test.

Thermoelectric generator generates DC type of electric power depending upon the temperature difference across the heat exchanger and the amount of exhaust gas temperature on Seebeck effect. An output voltage of 6.35V was generated using a single Bi_2Te_3 thermoelectric generator for a temperature difference of about 35^0C. This power is useful for running various accessories like head light, tail light, parking light, door light etc. Use of thermoelectric generator also reduces frictional power against alternator which in turns saves fuel and increase the efficiency of the engine. Results obtained from the present study states the concept of waste heat recovery where power is obtained to fulfill various auxiliary features.

Key Words: Exhaust gas temperature, Morse test, S.I. engine, Seebeck effect, Temperature difference, Thermoelectric generator, Waste heat recovery, etc.

1. INTRODUCTION

A thermoelectric generator is a solid state device that directly converts thermal energy (heat) due to a temperature gradient into electrical energy based on "Seebeck effect". The electrical power used in automobiles is generated using a part of the energy converted into a driving force with an alternator. The main problem of this energy conversion is that only part of the energy supplied by the fuel in an engine is converted into brake power output and although the efficiency of the alternator is high. The efficiency of a modern internal combustion engine is about 37% in a normal passenger car spark ignition engine. A significant amount of energy is lost to the environment. To overcome this loss the alternator size, load of engine power and engine weight are becoming larger. However, the engine room is becoming smaller in order to improve the aerodynamic characteristic and expand the passenger room. Hence the space for the alternator cannot be freely increased.

In recent years lots of study is being done on better fuel efficiency in automotive industry. About 40% of the heat energy supplied to an IC engine is rejected in the exhaust as waste heat. Out of this 40% rejected energy, around 6% can be efficiently reused in terms of electrical power which evidently reduce the fuel consumption by around 10%. Considering this fact, use of TEG becomes profitable in the automobile industry. The temperature of exhaust gas pipe of an engine is very high when exhaust gases are flowing through it and that is around 300^0 C to 600^0 C. Thermoelectric modules are ideal for such applications as they are small, with no moving parts and relatively efficient at this temperature.

1.1 Thermoelectric Generator (TEG)

A TEG comprises of mainly three main parts, the thermocouples, the hot side and the cold side. In this thesis the material of TEG used is bismuth telluride which is employed at an automotive exhaust gas system, by using the vehicles exhaust gas as the heat source and the coolant as the cold sink.

Seebeck Effect

The Seebeck effect states that whenever two dissimilar thermoelectric materials are joined into a loop, with the two junctions maintained at different temperatures, a temperature induced electrical potential also known as electromotive force (emf) is generated. The generated electromotive force represents the Seebeck voltage Voc and is written as

$$V_{oc} = \alpha AB \Delta T \qquad (1.1)$$

Where, αAB ($V\ K^{-1}$) represents the relative Seebeck coefficient of conductors A and B. ΔT represents the temperature difference between the junctions. The voltage is proportional to the temperature difference and depends on the type of conduction material, though it is not a function of the temperature distribution along the conductor.

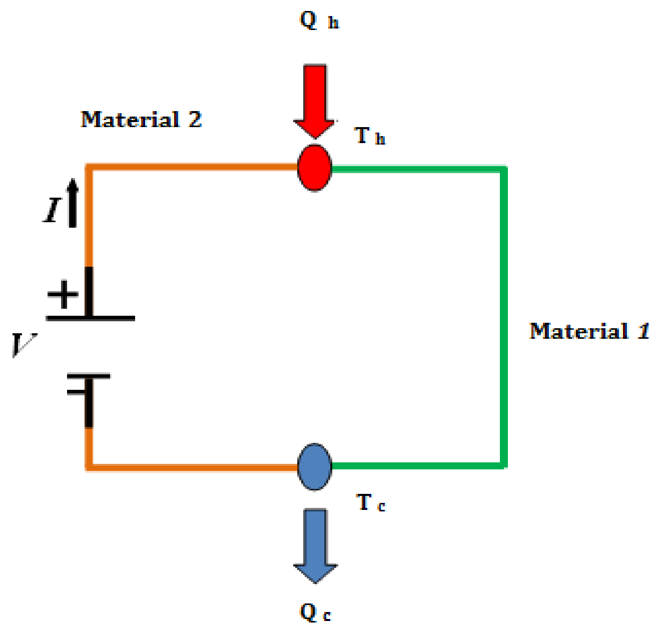

Fig- 1: Schematic of the Seebeck effect represented on a thermocouple.

The Seebeck effect shown in figure 1 is a basic principle of thermoelectric and is of considerable practical importance for creating an efficient thermoelectric generator. Semiconductors are often used as thermoelectric materials. Thermoelectric materials are materials that show the required properties which enable them to be used to convert thermal energy into electricity and vice versa. Often, impurities are added to semiconductors, a phenomenon known as "doping", with the aim of increasing the number of charge carries within it. There are two main types of doping, the negative type (n-type) and the positive-type (p-type). In the first type of doping valence electrons are added and in the second type, valence electrons are removed. When a semiconductor is subjected to two different temperatures at their ends, together with the heat flow through the pellets, the charge carriers flow in the same direction, from the warmer side to the colder. In the n-semiconductor the electrons will tend to migrate towards the cold side, and in the p-semiconductor leg the holes will move toward the cold side. This creates a voltage gradient between the legs. It is worth noting that the Seebeck effect is a contact phenomenon that only occurs through connection of two dissimilar thermoelectric materials.

1.2 Objective

From the literature reviewed in the previous section, it can be recognized that most studies have mainly focused on the analysis of the heat exchanger, exhaust waste heat recovery of internal combustion engines and the thermocouples separately.

Subsequently, to fill this gap, the objective of the present study is to investigate experimentally the power generated from the exhaust gas of a four stroke S.I. engine using bismuth telluride (Bi_2Te_3) thermoelectric generator at different gears and cylinder cutoff. The present study also aims to investigate various engine performances and TEG performances. This study also helps to estimate the output power which can be expected from these thermoelectric generators when applied in the exhaust gas system of the vehicles. A first estimation of the TEG's system efficiency and the TEG's recovery efficiency should also be presented. Additionally, the thermocouple's influence on the TEG should be investigated.

1.3 Waste Energy Recovery

Waste heat from the exhaust gas from the vehicle accounts for a considerable portion of the fuel energy that is not utilized is about 40% . Therefore a mean to improve to the fuel economy is to increase the overall efficiency of the power train by recovering waste heat from the exhaust gas of the vehicle. According to "1999 bosch automotive electric and electronics hand book" the average electrical power consumption of an automobile is about 600 watts. This load is carried by an in efficient engine/alternator system. The objective is to reduce the load on the alternator and consequently on the engine by converting the waste heat from the exhaust gas of the vehicle into electrical energy.

2. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Experimental Setup

Few key types of equipment used to conduct the experiment are:-

Four stroke-four cylinder petrol engine, thermoelectric module, thermal paste at the heat sink with fan, flexible joint and millimeter, temperature gun, booster circuit, water block, submersible D.C. pump.

2.1.1 Four Stroke-Four Cylinder Petrol Engine

Four stroke-four cylinder Maruti Zipsy's petrol engine is used to perform the experiment. The fuel used in the engine is petrol and the rated power of the engine is 10HP at 1500 rpm. The arrangement of the cylinders is inline. The bore diameter of cylinder is 68 mm and the stroke length is 75 mm. The compression ratio is 7.8:1. The diameter of the orifice is 26 mm. The specific gravity of the fuel used is 0.69 gm/cc and the calorific value is 10650 Kcal/kg. The coefficient of discharge is 0.62.

Fig- 2: Four stroke-four cylinder petrol engine.

The engine performance depends on the interrelationship between power developed, speed and specific fuel consumption at each operating condition within the useful range of speed and load. In order to calculate the above parameters, following are the aspects need to be given considerations:-

Fuel consumption measurement: The fuel is supplied to the engine through a graduated fuel gauge with a three way cock between main tank and carburetor.

Air consumption measurement: The suction side of the cylinder is connected to an anti- pulsating air chamber. A manometer is provided to measure the pressure drop across an orifice of 20 mm diameter provided in air inlet pipe of air tank. This pressure drop is used to calculate the actual mass flow rate of into the cylinder.

Loading of engine: The engine test rig is directly coupled to a hydraulic dynamometer, which is loaded by water flow into the dynamometer at constant head pressure. Operating gate valve provided on the inlet inline of dynamometer can vary the load.

Exhaust gas calorimeter: Exhaust gas from the engine is passed in an exhaust gas calorimeter. Calorimeter is shell and tube type heat exchanger, which is used to find the quantity of heat taken away by exhaust gases.

Temperature measurement: The temperature of exhaust gas entering and leaving the calorimeter engine cooling water inlet, outlet and ambient temperature are sensed by thermocouple and directly indicated on a digital temperature indicator.

Water flow measurement: Two Rota meter are provided at the engine jacket and exhaust gas calorimeter to measure the quantity of water allowed into the engine jacket as well as calorimeter.

2.1.2 Thermoelectric module

Heat energy is converted directly into electricity by using the thermoelectric – TEP-1264.1.5 power module which is designed and manufacture for this purpose. Bi-Te based thermoelectric module is used in this experiment that can work at the temperature of as high as 330^{0}C (626F) heat source continuously, and up to 400^{0}C (752 F) intermittently. As a result, based on the temperature difference, DC power is generated. This phenomenon triggers the power generation in a more efficient manner as the temperature difference is increased. Graphite sheets with high thermal conductivity are placed on both sides of ceramic plates. Apply thermal grease or other heat transfer compound while installing the thermoelectric module to provide low contact thermal conductivity. Graphite sheets are used because they can work in extremely high temperature also.

The material used is Bismuth telluride and the type is thermoelectric generator. Dimension of the module is 40 mm x 40 mm x 3.5 mm and the recommended operating temperature range is – 40^{0}C to 150^{0}C. The module comprises of 127 couples and the cable length is approximately 20 cm.

Fig-3: Thermoelectric power module.

2.1.3 Thermal paste at the heat sink with fan

Thermal grease (also called CPU grease, heat paste, heat sink compound, heat sink paste, thermal compound, thermal gel, thermal interface material, or thermal paste) is a viscous fluid substance, originally with properties similar to grease, which increases the thermal conductivity of a thermal interface between heat sinks and heat sources by filling microscopic air-gaps present due to the imperfectly flat and smooth surfaces of the components. The main role of thermal grease is to eliminate air gaps or spaces from the interface area so as to maximize heat transfer. The compound has far greater thermal conductivity than air (but far less than metal). In electronics, it is often used to aid a component's thermal dissipation via a heat sink.

2.1.4 Flexible joint and Multimeter

Multimeter is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter can measure voltage,current, and resistance. Digital multimeters display a numeric value.

Digital multimeters are now far more common due to their cost and precision. We are using for measure the voltage and current.

2.1.5 Thermometer

A thermometer is a device that measures temperature. A thermometer has two important elements: (1) a temperature sensor in which some physical change occurs with temperature, and (2) some means of converting this physical change into a numerical value. To capture the exhaust temperature of the engine, a digital thermometer was used..

2.1.6 Booster circuit

A booster circuit is a DC-to-DC power converter used to step up the voltage alongside stepping down current from its input (supply) to its output (load). It is a type of Switched-Mode Power Supply (SMPS) which contains at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter) to reduce voltage ripple. This is based on the theory that inductor holds current and passes in opposite direction. It has a poor efficiency of 60-80%. So can't be used for a large project. It can be used for low power consuming models like 12 V and 3 V models which requires 250 mA current. 650 mA have to be spending with 80% efficiency. In this circuit DC pulse of around 2V is applied through TEG and amplifying to 12 V as output. Follow the below for expected voltage range 6V to 12V @ 1A : 80 turns of 24 swg wire in a 0.5 mm ferrite core 6V to 12V @ 500 mA : 60 turns of 36 swg wire in a 0.5 mm ferrite core.

2.1.7 Water block

A water block is the water cooling equivalent of a heat sink. It consists of at least two main parts; the "base", which is the area that makes contact with the device being cooled and is usually manufactured from metals with high thermal conductivity such as aluminum or copper. The second part, the "top" ensures that the water is contained safely inside the water block and has connections that allow hosing to connect it with the water cooling loop. The top can be made of the same metal as the base.

2.2 METHODOLOGY

2.2.1 Setup to Harness Energy from Engine Heat

Parts required an engine with an exhaust system, a generator, a rechargeable DC battery and mild steel for constructing frames, connecting wires, a thermocouple unit, metal clamps (stainless steel screw).

2.2.2 Working Procedure

The vehicle is started and the acceleration is to be given, so that the amount of heat leaving the exhaust will be increased. This results in the excessive heat up of the surface of exhaust pipe which ultimately is dumped into the atmosphere. The atmospheric temperature is less than that of the silencer surface which creates a temperature difference and the surface tries to attain the equilibrium state through the heat transformation process. This equilibrium state will be maintained in much longer time. Hence in order to increase the rate of heat transfer the thermal grease is used. The hot surface of the silencers and the inner surface of the fins which are present in the upper part are coated with thermal grease. The fins are also used to increase the heat transfer rate. Due to the air flow between the fins, it acts as the sink when the vehicle is running.

As the surface of the silencer gets more and more heated the heat transfer rate will increase due to the increase in the temperature difference. The TEG module is placed between the Heat Source (Hot Silencer Surface) and the Heat Sink (atmosphere) and the fins are placed above the module. The module is made of semiconducting materials. The temperature difference can be directly converted into voltage by using some thermoelectric materials working on the principle of Seebeck effect. Based on this effect, when the surface heat of the silencer 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 buck Converter. This will step up the voltage generated to some nominal value. So that sufficient amount of voltage can be obtained. For this converter the general formula used to measure the approximate voltage for 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. The following steps are to be considered for performing the experiment:

- The hottest part of the exhaust system is identified. This would likely be on the exhaust pipe.
- The thermocouple is clamped on to the spot, such that one side is exposed to heat, while the other side is exposed to atmosphere. This provides the temperature difference required to generate electricity.
- Leads from the thermocouple are connected to the battery via inverter, which would be stored in a DC rechargeable battery of matching capacity (12V, 5A).
- The entire setup is to be housed on the exhaust pipe. For this purpose, the exhaust pipe is dismembered; the casing is mounted, and fixed back.

2.3 RESULTS AND DISCUSSION

2.3.1 Results

A. Engine Performance

Based on the observations and calculations done for 1st Gear, the engine performance parameters founded are as follows-

- The Brake Power of the engine was found to be 0.441kW.
- The Indicated Power of the engine was found to be 0.610kW.
- The Friction Power of the engine was found to be 0.169kW.
- The Specific Fuel Consumption of the engine was found to be 8.69kg/kWhr.
- The Mechanical Efficiency of the engine was found to be 72.79%.
- The Brake Mean Effective Pressure of the engine was found to be 32.39kPa.
- The Indicated Mean Effective Pressure of the engine was found to be 44.81kPa.

B. TEG Performance

As the mass flow rate of the exhaust gas increases, power and efficiency of Thermoelectric Generator also increases at different gears as shown in the table below.

Table 1 Performance of TEG at different gears.

Gear	Mass Flow Rate of Fuel (10^{-3} kg /sec)	Mass Flow Rate of Exh. Gas (10^{-3} kg/sec)	Power Input in T.E.G. (W)	Power Output from T.E.G. (W)	T.E.G. Efficiency (%)
Gear 1	1.065	15.515	232.72	04.68	2.01
Gear 2	1.997	16.447	441.17	09.88	2.24
Gear 3	4.493	18.943	568.29	16.32	2.87
Gear 4	6.536	20.986	734.51	21.59	2.93

2.3.2 Discussions on Results Achieved

Chart 1 shows the effect of exhaust gas temperature on TEG power. Power developed across T.E.G. increases with the increase in exhaust gas temperature. Graph between exhaust gas temperature and power depicts that power is the function of exhaust gas temperature. A maximum power of 4.68 Watts is obtained at an exhaust gas temperature of 315^{0}C in first gear.

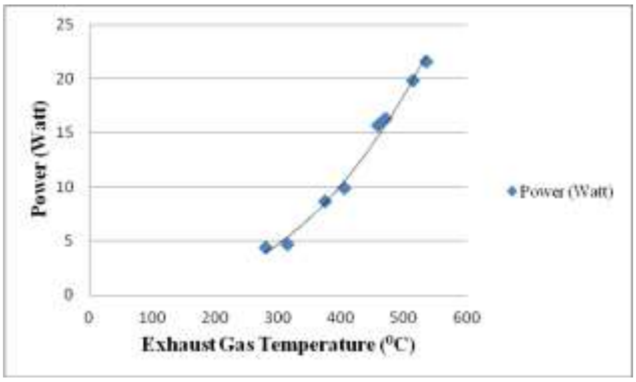

Chart 1: Effect of exhaust gas temperature on output Power.

Chart 2 shows the effect of temperature difference on output Power across T.E.G. Power increases with the increase in temperature difference. Graph between temperature difference and power depicts that power is the function of temperature difference. A maximum power of 4.68 Watts is obtained at a temperature difference of 15^{0}C in first gear.

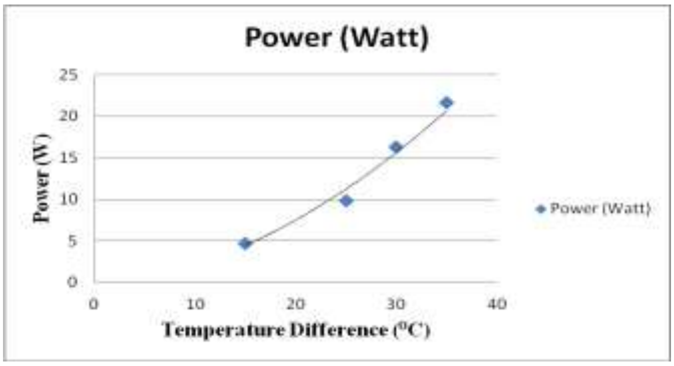

Chart 2: Effect of temperature difference on output Power.

Chart 3 shows the effect of temperature difference on T.E.G efficiency. Efficiency increases with the increase in temperature difference. Graph between temperature difference and efficiency depicts that efficiency is the function of temperature difference. A maximum efficiency of 2.01% is obtained at a temperature difference of 15^{0}C in first gear.

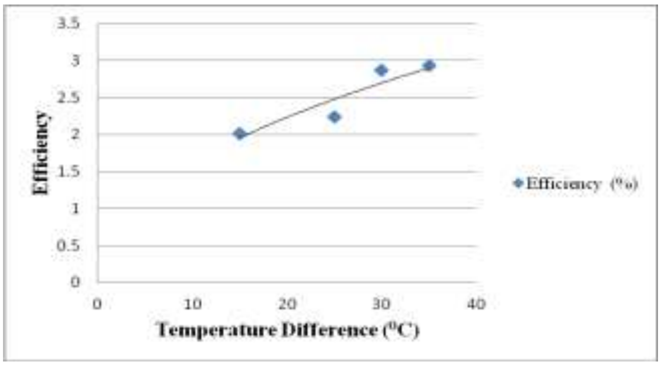

Chart 3: Effect of temperature difference on efficiency.

Chart 4 shows the effect of mass flow rate of exhaust gas on T.E.G efficiency. Efficiency increases with the increase in mass flow rate of exhaust gas. Graph between mass flow rate of exhaust gas and efficiency depicts that efficiency is the function of mass flow rate of exhaust gas. A maximum efficiency of 2.01% is obtained at a mass flow rate of exhaust gas of 0.0155 kg/sec in first gear.

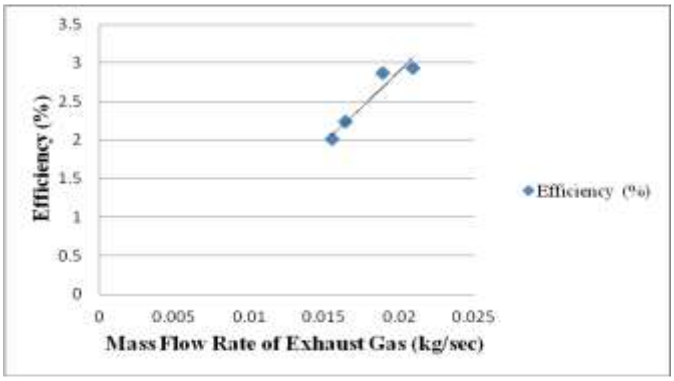

Chart 4: Effect of mass flow rate of exh. gas on efficiency.

2.4 Sample Calculations

Power intput to TEG ($Q_{i/p}$) = $\dot{m}_g \times C_{pg} \times (T_{h1} - T_{h2})$

$$Q_{i/p} = 15.515 \times 10^{-3} \times 1 \times (315 - 300)$$

$$Q_{i/p} = 232.72 \text{ W}$$

Efficiency of TEG

$$\eta = \frac{Qo/p}{Qi/p}$$

$$\eta = \frac{4.68}{232.72}$$

$$\eta = 2.01\%$$

3. CONCLUSIONS

Experiment have successfully performed on four stroke four cylinder Petrol Engine by using thermoelectric generator and studied all the required components for it along with their working. After doing experiment one can conclude that such type of system of waste heat recovery is feasible. Results show that-

1. Output current, voltage and power increases with the increase in exhaust gas temperature.
2. With increase in mass flow rate of exhaust gas efficiency also increases.
3. With increase in temperature difference power and efficiency also increases.
4. As the brake power increases temperature difference and exhaust gas temperature also increases.
5. Variation of current with voltage.

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REFERENCES

[1] Vázquez, J., et al., State of the Art of Thermoelectric Generators Based on Heat Recovered from the Exhaust Gases of Automobiles, Proceedings, 7th European Workshop on Thermoelectrics, Paper 17, Pamplona, Spain, 2002.

[2] Madhav, A. K., et al., Thermoelectrical Energy Recovery from the Exhaust of a Light Truck, Proceedings, 2003 Diesel Engine Emissions Reduction Conference, Newport, R. I., USA, 2003.

[3] P. Mohamed Shameer1, D. Christopher,“Design of Exhaust Heat Recovery Power Generation System Using Thermo-Electric Generator”-International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438, Volume 4, Issue 1, January 2015

[4] C. Lu, S. Wang, C. Chen and Y. Li. Effect of heat enhancement for exhaust heat exchanger on the performance of thermoelectric generator. Applied Thermal Engineering, 89:270–279, 2015.

[5] S. Bai, H. Lu, T. Wu, X. Yin, X. Shi and L. Chen. Numerical and Experimental analysis for exhaust heat exchangers in automobile thermoelectric generators. Case Studies in Thermal Engineering, 4:99–112, July 2014.

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