Using Thermoelectric Generators to Utilize Heat generated in Disc Brakes

Prakhar Tonk, V.K Singh, Naman Jain

G. B. Pant University of Agriculture and Technology, Pantnagar

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Abstract- *Generating electric power in an automobile through engine is a highly inefficient process. It comes as a direct result of consuming fuel within the engine to drive the alternator. With a typical engine efficiency of 40%, a belt efficiency of 98% and an alternator efficiency of 75%, this leads to an overall energy conversion efficiency of only 29%. Many automobile components require electricity to run and thus generation of electricity in an efficient manner will help reduce the fuel costs and ultimately lead to lesser carbon emissions. In this paper, we will discuss utilizing the heat generated in the brakes during heating by using Thermoelectric Generators (TEGs) which are based on Seebeck Effect. The electrical power produced with the help of TEGs will help in reducing the load of alternator on the engine, thus reducing the fuel consumption. This electricity produced can also be used to replace other auxiliary devices which take power directly from the engine to electrically powered such as fuel pump, water circulating pump, radiator, power steering pump etc. which take up to 8% of indicated output from the engine.*

Key Words: Disc Brake; Seebeck Effect; Thermoelectric Generator; Finite Element Analysis; Automobile

1. INTRODUCTION

An automobile has many electrical components which are run on electric power generated by the alternator and stored in the battery. These components are starter motor[1], wiper motor, fuel pump, distributor, headlamps, tail lamps, air conditioning fan etc. As the engine rotates, a belt drive powers the alternator which produces electricity. It consumes engine output power in the process. We can reduce this power consumption by producing electricity from utilizing the heat generated in the brakes[2]. Thermoelectric generators use Seebeck Effect[3] to produce electricity. Installing these TEGs on the inner surfaces of brake discs would produce electricity which can then charge the battery, which would eventually reduce the alternator load on the engine and result in a better fuel economy.

Alternators are used in automobiles to charge the battery and to power the electrical system when its engine is running. The electrical requirements of an automobile are fulfilled by connecting an alternator to the engine by a belt. As the engine runs, the aperture of the alternator moves, thus generating electricity. This electricity produced charges the battery of the automobile, which then runs all the electronic equipments. For a typical alternator, the electricity supplied to the battery is 15-55A at 12V[4], i.e. 180-660W. Efficiency of alternator is given by

$$\eta = P_{out}/P_{in} \qquad (1)$$

Where,

η = alternator efficiency,

P_{out} = electrical input power,

P_{in} = mechanical output power

η is found to be varying from 70-80%[5]. Assuming 75% efficiency, engine power consumed by alternator will be 240-880W. This is a significant amount considering a normal engine producing 25kW, such that the alternator load is 1 to 3.5%. Significant reduction in this load can be achieved by producing electricity from brake heat as the battery will be charged without the use of alternator, thus causing significant improvement in fuel economy.

1.1. Seebeck Effect

The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit.

1.2. Thermoelectric Generators

A thermoelectric generator (TEG), also called a Seebeck generator, is a solid state device that converts heat flux (temperature differences) directly into electrical energy through the phenomena of Seebeck effect. Thermoelectric generators could be used in power plants in order to convert waste heat into additional electrical power and in automobiles as automotive thermoelectric generators (ATGs) to increase fuel efficiency. Another application is radioisotope thermoelectric generators which are used in space probes, which has the same mechanism but use radioisotopes to generate the required heat difference. Automotive Thermoelectric Generators use the waste heat of exhaust gases. The exhaust gases are passed through a heat exchanger which is connected to ATGs to generate power. Although these are successful in improving the fuel efficiency by 4%[6], the flow of exhaust gases through heat exchanger causes increase in exhaust manifold pressure thus increasing the work done by the engine during exhaust stroke, thus reducing the efficiency. We intend to use the heat generated in the brakes of an automobile and convert it into electric energy by means of TEGs to charge the batteries, thus reducing the alternator load on the engine, thus improving fuel efficiency. The TEG to be used in the following is that of 'Everredtronics'. We will take the data from the 56*56mm module(Appendix 1), for which the data sheet is provided by the manufacturer.

2. MATERIAL AND METHOD

2.1. Modeling of Brake Disc

Using Solid Works, we designed the discs which will be analysed in the given problem. We designed a disc such that TEGs can be installed inside the cavity between the two plates (Figure (a)). First, we draw the outer circle of the disc of 280mm diameter as in Figure 1(b). Then, constructing a smaller circle on the same centre of 150mm diameter, we extrude cut inverse such that the hollow cavity is produced as shown in Figure 1(c). Then, producing the support ribs (Figure 1(d)) and the outer support for attaching to the wheel hub (Figure 1(e)), we obtain the final model of the disc shown by Figure 1(f).

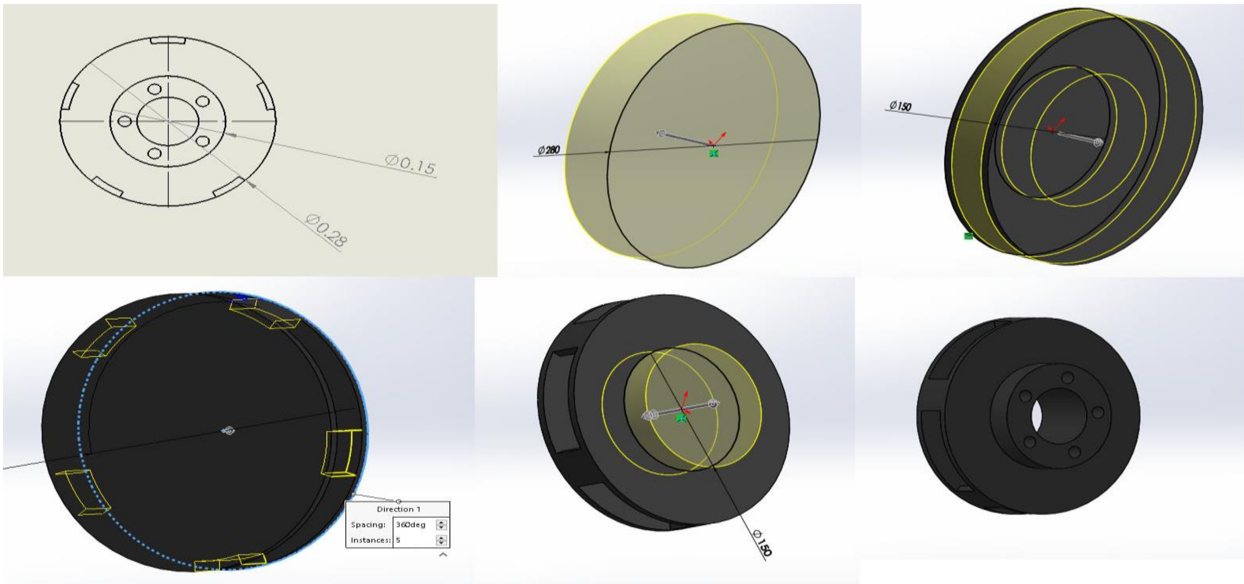

Figure-1: (a) Initial sketch of disc, (b)Outer circle extrusion, (c)Inner circle extrude cut, (d)Support Ribs, (e)Hub support and (f) Disc final model

Table- 1: Properties of Cast Iron

Property	Value
Density (kg/m^3)	7810
Coefficient of Thermal Expansion, α(°C^{-1})	1.2E-05
Specific Heat (J/°C kg)	506
Thermal Conductivity (W/m °C)	45

The material used is Cast Iron, which is the material used in most disc brakes. The material properties of cast iron are as shown in Table 1[6]:-

2.2. Modelling of TEG

TEG consist of small 2*2mm sized cells which can be arranged in the required pattern. For installation in brake discs, the elements can be as shown in figure 2:-

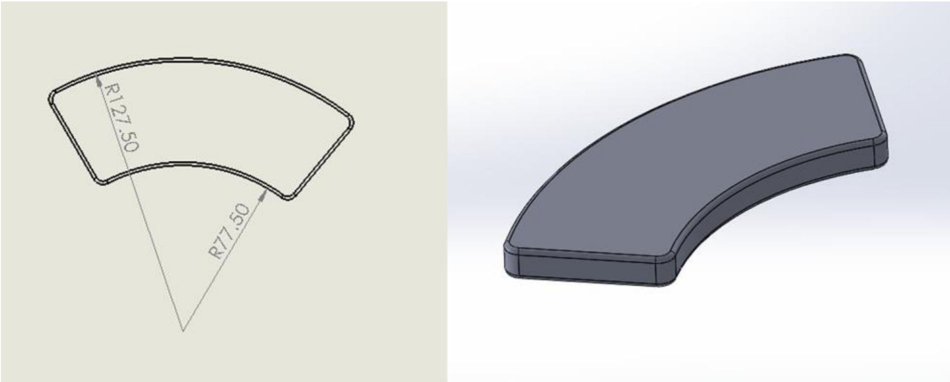

Figure- 2: (a)Initial sketch of TEG unit, (b)Final model of TEG unit

2.3. Meshing

Meshing is done using ANSYS, taking relevance centre as fine, high smoothing and span angle centre as fine. The design domain is discretized into 23574 elements and 41960 nodes[9]. The result is shown in Figure 3.

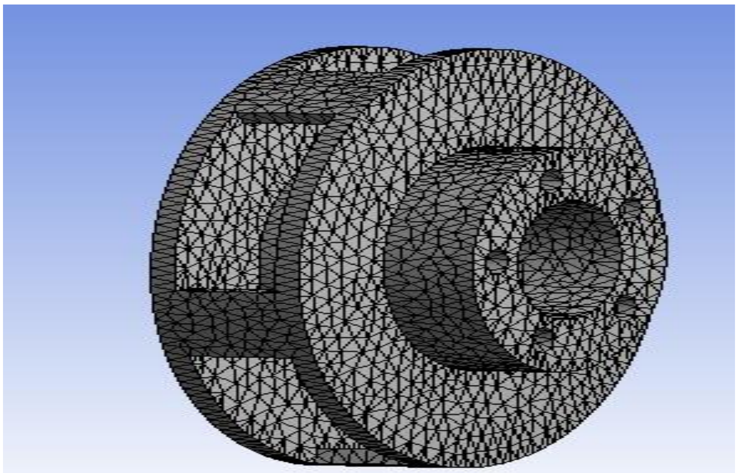

Figure- 3: Meshed disc

2.4. Disc Brakes Analysis

Taking the case for Maruti Swift, the calculation for heat generation and surface temperatures can be done.

Mass of vehicle- Kerb- 855-880kg

Gross- 1315kg

Assuming a braking condition of deceleration from 80kmph to 0kmph in 5 seconds,

Initial velocity, u= 80 kmph= 22.22 m/s

Final velocity, v= 0 m/s

Assuming uniform brake force distribution on all 4 wheels, (Total load on 1 brake)/(total load) = ¼ = 0.25 = β

And fraction of kinetic energy absorbed by the brakes, k= 0.9

The energy generated during braking will be-

$\Delta K.E. = \beta \cdot k \cdot \frac{1}{2} \cdot m\,(u^2 - v^2)$ (2)

$= 0.25*0.9*0.5*1315*(22.22^2 – 0)$

= 73040.94 J

Braking Power, P_b = K.E./t = 73040.94/5 = 14608.19 W.

This braking power will be distributed equally among the two outer surfaces of the disc which will be applied by the brake shoes. For determining the temperature conditions of the disc, we will apply constant heat flow of 7442.95W on both the surfaces.

1. Assigning constant heat flow[10] of 7442.95W on both the surfaces as shown in figure 4.

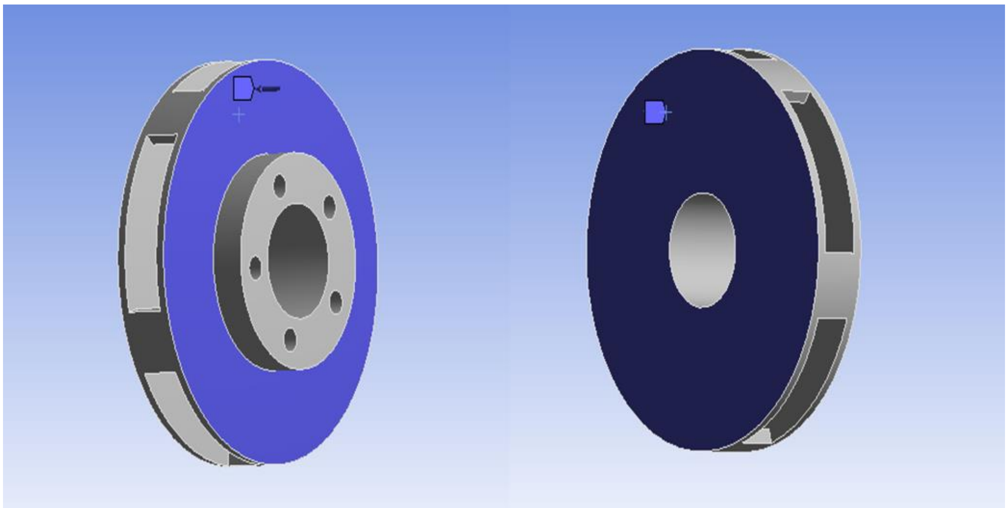

Figure- 4: (a)Heat flow on the first surface, (b)Heat flow on the second surface

2. Applying convection condition for the surfaces exposed to air[11], taking ambient temperature as 22 ^{o}C as shown in Figure 5.

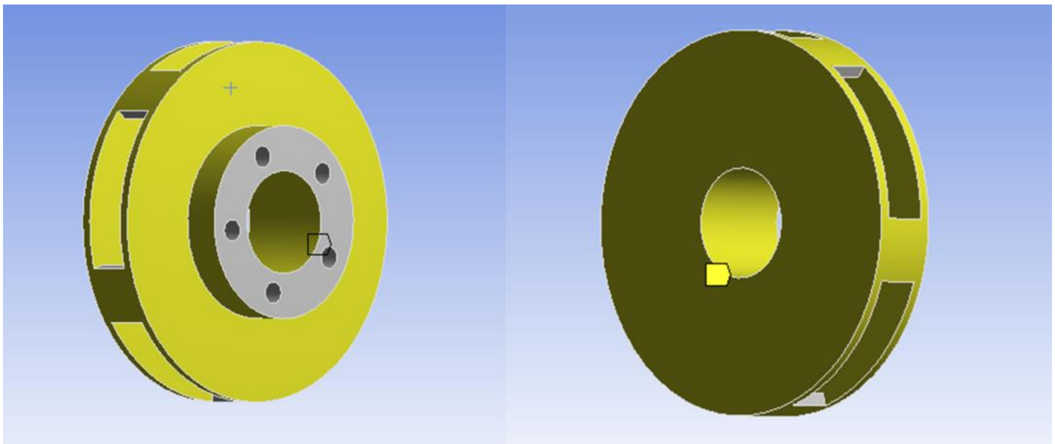

Figure- 5: Convection conditions applied on the surfaces exposed to air

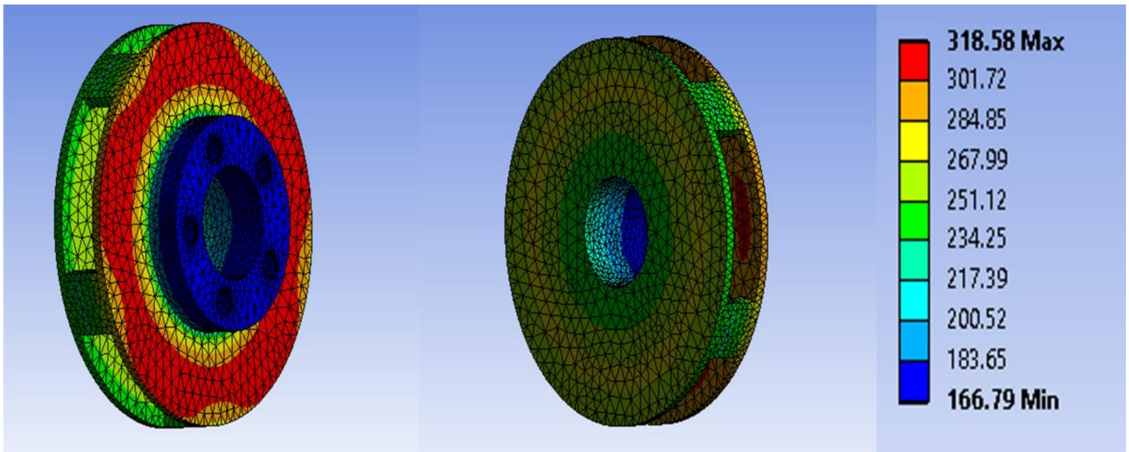

Figure- 6: Temperatures of different zones in a disc

3 RESULTS AND DISCUSSIONS

3.1. Thermal Analysis of Brake Disc

In order to calculate the power produced, we calculated the temperatures of a disc brake during normal breaking instances[7]. We analysed the disc brakes temperature by using ANSYS (Thermal)[8]. We got solution for temperature. The results were as shown in Figure 6:-

From the obtained results we can take the mean temperatures of inner side of the brake disc to be 300 ^{o}C. This surface will serve as the hot side of the TEG. Five such TEGs can be installed on both sides of the inner surface of the discs. The installation of the TEG on the disc can be shown in Figure 7:-

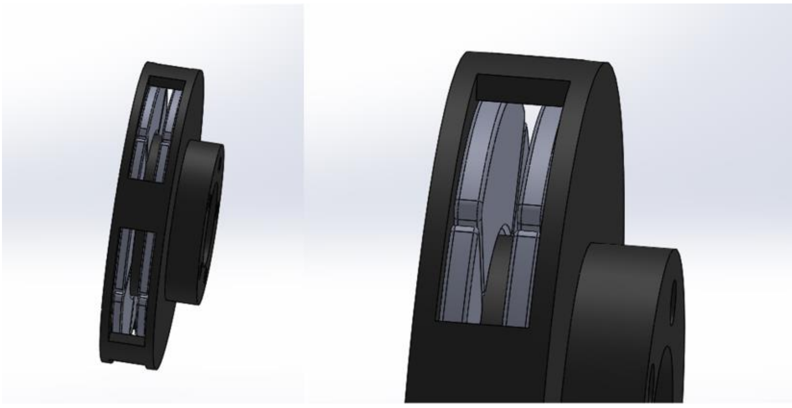

Figure- 7: Installation of TEGs on the inner sides of the disc

3.2. TEG Calculations

The area on which TEG will be installed can be calculated as follows:-

$A = 2 * \pi/4(D_o^2 - D_i^2) = 2 * \pi/4\ (255^2 - 155^2) = 64402.65\ mm^2$. Taking 'Everred Electronics TEG 241-60B',

Max Temperature- 320 °C.

Thermal Conductivity- 3W/mK (Bi_2Te_3)

Dimensions- 56 * 56 mm

For one module, the power produced when hot side is at 300°C and cold side is at 50 °C is 19.7 W for a TEG module of size 56*56mm, i.e. an area of 3136 mm². For 64402.65 mm², power produced from one brake will be 404.57 W and power produced from 4 brakes will be 404.57 * 4= 1618.28W.

3.3. Fuel Saving Calculations

From the diesel to power conversion chart, we can determine the amount of fuel saved per hour. Taking half of the power produced theoretically to charge the battery, i.e. 809.14, and taking 75% efficiency of alternator, 1078.85 W of engine power is saved. We can calculate the fuel saved by referring to the Brake Specific Fuel Consumption of a gasoline engine, which is 250g/kWh. We can further calculate the results based on the drive time in hours per day and the number of days driven per year. The results are as shown in Table 2.

Table- 2: Fuel Savings Table

Running time per day (hrs)	Number of days	Mass of fuel saved (kg)	Fuel saving (ltr)	Rate of fuel (INR/ltr)	Total cost saving (INR)
1	200	53.94	70.05	70	4903.864
	300	80.91	105.08		7355.795
1.5	200	80.91	105.08	70	7355.795
	300	121.37	157.62		11033.69
2	200	107.88	140.1104	70	9807.727
	300	161.83	210.1656		14711.59
2.5	200	134.85	175.138	70	12259.66
	300	202.28	262.707		18389.49
3	200	161.82	210.1656	70	14711.59
	300	242.74	315.2484		22067.39

4. CONCLUSIONS

From the above results we find that significant reductions in fuel consumption can be achieved by using TEGs in disc brakes. This generated heat is otherwise wasted to the atmosphere. This can have significant carbon emission reduction which can help reduce the adverse effects of global warming. Apart from the reduced load on the alternator, other equipments such as AC compressor, power steering pump etc. can be powered electrically rather than directly from the engine to further reduce auxiliary loads on the engine.

Appendix

Data sheet for TEG

TEG P/N	Length	Width	V/K	Open Circuit V	Matched Output Voltage	Matched Output Current A	Matched Output Power W
TEG126-30A	30	30	0.0396	9.91	5.1	0..97	4.9
TEG126-40A	40	40	0.0396	9.91	5.2	0.98	5
TEG126-60A	56	56	0.0311	7.78	4	3.36	13.2
TEG241-60A	56	56	0.0652	16.3	8.5	1.96	16.5

TEG126-30B	30	30	0.0333	8.33	4.4	1.52	6.7
TEG126-40B	40	40	0.0267	6.67	3.58	1.9	6.8
TEG126-60B	56	56	0.0311	7.78	4.12	4.4	18
TEG241-60B	56	56	0.0533	13.33	7	2.84	19.7

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AUTHORS

Prakhar Tonk
Pursuing Bachelor of Technology In Mechanical Engineering from G.B. Pant University of Agriculture and Technology, Pantnagar, India. His areas of interest are finite element analysis, thermal conduction and automobiles.

Naman Jain

Naman Jain obtained his Master degree in Design and Production Engg. From G. B. P. U. A & T. He is currently pursuing Ph.D. in Mechanical Engineering from G. B. P. U. A & T. His areas of interest are finite element analysis, computer aided mechanical design, optimization and Numerical Modeling and Simulation.