TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 1997 - 2002

Harvesting Energy from an Exhaust System using High Temperature Thermoelectric Material

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Article Info
Volume 82
Page Number: 1997 - 2002
Publication Issue:
January-February 2020

Abstract

Many systems in the aircraft are powered by the normal generator that is existing in the gas turbine engine. However, some of the systems such as the A/C auxiliary charging system (USB) are overloaded. This thing leads the APMS to isolate or switch off the USB system in order to save the power for the other systems which are more in needed to the power than the USB system. Besides that, this research presents the way of harvesting the energy from the exhaust system using a high-temperature thermoelectric material. The purpose of this research is to design and test the thermoelectric generator in the exhaust area of the gas turbine engine to see whether it can power the A\C auxiliary charging system individually. This system consists of mechanical and electronic components including 14 thermoelectric generators that are tested under several numbers of temperature and the interfaces to the exhaust system of the gas turbine engine. The gas turbine engine whose operating conditions was used for this research is based at Universiti Pertahanan Nasional Malaysia (UPNM). From the overall result that produces from this study, the highest voltage which is 10V is produced at the temperature of 250 degrees Celsius during the 14 TEGS experiment. This amount of voltage is too high for A/C auxiliary charging system, so it is advised to have a voltage regulator in order to convert this amount of voltage into the optimum amount. Moreover, this amount of voltage can be increased by increasing the number of the TEGs and the temperature. This project will give advantages to the user such as the airlines to utilise the wasted heat that is existing in the exhaust section into a useful renewable energy.

Keywords: Energy Harvesting; Aircraft Exhaust System; Thermoelectric Material.

Article History
Article Received: *14 March 2019*
Revised: *27 May 2019*
Accepted: *16 October 2019*
Publication: *11 January 2020*

1. Introduction

Everyone needs an energy such as (an electricity) in his or her life. Moreover, most of the energy nowadays is producing by using generators such as electromechanical generators. These generators are powered by using the fuel. So as we know that, the emission Co2 is increasing from year to another year which is playing a largely negative role on the earth. So, the experts start to think of a new way of producing an energy (electricity) without being affected on the surrounded environment. Furthermore, the experts come up with a new technology of energy which it can be produced without using any type of fuel. This energy calls a renewable energy/ clean energy. It comes from the natural sources such as wind, water, etc. Therefore, numerous studies by previous researches have been done using different methods to understand this type of renewable energy and to comprehend the effects of the GTE on this system. However, detail observation of implementing the TEGs in GTEs can be achieved by a reliable numerical simulation

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or by doing an experiment. As can be seen, there are lots of published numerical simulation methods [1], [2], [3] but there is no paper had covered the experiment one. On the other hand, in this research, we are going to do a study about how to produce an electricity based on the difference in temperature by using the thermoelectric material [4], [5], [6], [7] in order to power an aircraft's system separately without being affected on the other aircraft systems entitled harvesting energy from an exhaust system using [8], [9], [10] high temperature thermoelectric material (Mckinsey, 2007). Thus, the objectives of this paper is firstly to build the new system to produce the wanted output power that is needed for turning on the A/C auxiliary charging system. Secondly is to test the new system to see whether it is able to produce an enough power to the A/C auxiliary charging system. Thirdly is to propose and recommend the optimal area of TEG in order to harvest more energy.

2. Experimental

The experimental of this research has been done in Universiti Pertahanan Nasional Malaysia (UPNM). This project basically relies on the difference in temperature between the hot and the cold sections. Moreover, there are some procedures should be followed during carrying out the test. These safety procedures can be found the MM. In addition, it designs by using a software that is called CATIA in uniKL MIAT Subang. The design contains on six essential sections which are cone, pipe, hot box, cold box, TEGs, and the exhaust section. The first section is the cone that is attached to the exhaust section of Jet Turbine Engine TGT020. The function of the cone is to gather as much as possible of the exhaust's hot gasses. The second section is the pipe. It is attached between the cone and the hot box. The function of it is to help in passing the hot gasses of the exhaust section into the hot box. The third section is the hot box. The purpose of this section is to gather the wanted heat that is needed for the TEGs to make it work in a good condition. The fourth section is called the TEGs. This section is the one that is responsible for converting the difference in temperature between the hot section and the cold section into power. It can bear up to 300 degrees Celsius. So, the higher the difference in temperature, the more power is going to be produced. The fifth section is the cold box. The aim of the section is to collect a cold air such as by putting ice inside the box. The last section the exhaust section. The purpose of this section is to allow the hot gasses to get out of the hot box. Furthermore, many issues have been faced during the first experimental. The project has been fall down due to high speed of the exhaust section of the Jet Turbine Engine TGT020. However, it has been sorted out by making a stand and attach it to the earth by screws. The second problem is the high temperature of the exhaust section which is around 250 degrees Celsius. This temperature is enough to cause the cables of the TEGS melted and effect on the function of TEGs. On the other hand, this issue has been fixed by using fiberglass cables. It works as a protector for the main TEGs cables. Additionally, these cables can bear up to 300 degrees Celsius. Besides that, another problem has been faced out during the experimental. The problem was related to the Jet Turbine Engine TGT020. The flow meter of the engine stopped working which causes the engine to be malfunctioned. Nevertheless, due to the long time needed for fixing this problem, the researcher and the supervisor decided to find a source that has the same amount of heat that is produced by the exhaust section of the of the Jet Turbine Engine TGT020 during its maximum operation which is 250 degrees Celsius. The Jet Turbine Engine TGT020 has been replaced with burner a device.

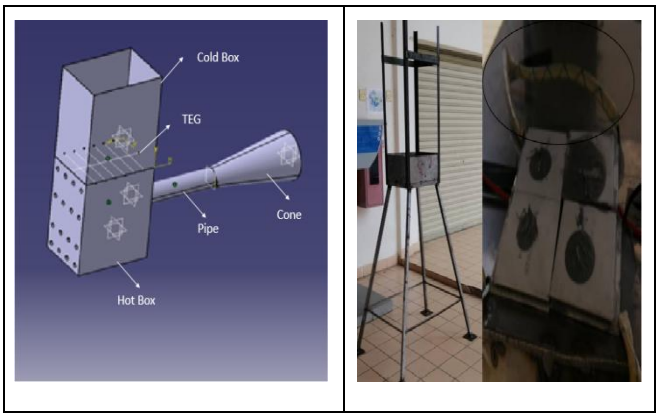

Figure 1: SIRAJ TEG and Solutions of the design

3. Results and Discussion

A. Analysis Table Using Jet Turbine Engine TGT020

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Table 1: Analysis Table

EXPERIMENTAL NUMBER	TIME(SEC)	TEG QUANTITY	Temperature (Celsius)			Output (Voltage)
	I.	**II.**	COLD SECTION	HOT SECTION	DIFFERENCE IN TEMPERATURE	**III.**
1	25	4	0	40	40	0.64

B. Result Analysis

Table above shows the result of the first experiment of SIRAJ TEG by using the jet turbine engine TGT020. The output voltage 0.64 is produced based on the difference in temperature between the cold section and hot section of SIRAJ TEG which is 40 degrees Celsius. Moreover, it takes around 25 seconds for the temperature to reach to 40 degrees. This time is considered good compared to other results from other studies. However, the rest of the data could not be collect due to the sudden malfunction in the jet turbine TGT020 that happened during the experiment. As a result, based on the data that shown in the above table, SIRAJ TEG can produce electricity by using the wasted heat in the exhaust section very effectively.

Table 2: Analysis Table

Experimental Number	Time (sec)	TEG QUANTITY	Temperature (Celsius)			Output (Voltage)
			Cold section	Hot Section	Difference in Temperature	
1	5	4	0	50	50	0.19
	9		0	100	100	0.45
	11		0	200	200	2.39
	35		0	250	250	4.43
2	9	8	0	50	50	1.26
	12		0	100	100	3.11
	15		0	200	200	6.38
	45		0	250	250	5.9
3	10	12	0	50	50	1.88
	13		0	100	100	5.28
	17		0	200	200	6.42
	50		0	250	250	7.03
4	11	14	0	50	50	2.12
	14		0	100	100	6.53
	20		0	200	200	9.05
	51		0	250	250	10

C. Analysis Table Using Alternative Heating Source

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Experiments had been conducted to observe the characteristic of SIRAJ TEG and the functional of this project. Additionally, 1 digital multimeter and 1 digital thermometer have been utilized in all of the experiments. Besides that, the duration of time of these experiments has been taken in one minute for each experiment.

D. Result Analysis

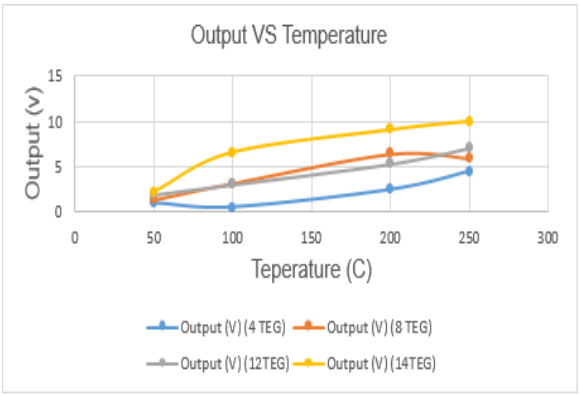

Figure 2: Graph of the output (Voltage) and Temperature for SIRAJ TEG

The graph above deals with the output of SIRAJ TEG and its temperature for all of the experiments. It describes the changing way of the output with the temperature. As well as that, the output differs from an experiment to another. For example, 50 degrees Celsius can produce 0.19 voltages in the experiment of 4 TEG, 1.26 voltages in the experiment of 8 TEG, 1.88 voltages in the experiment of 12 TEG and 2.12 voltages in the experiment of 14 TEG. In addition, for 250 degrees Celsius, the output during the experiment of 4 TEG is 4.43 voltages while the output for the experiment of 14 TEG is 10 voltages. To conclude this, the output of SIRAJ TEG is increasing with increasing in temperature and the quantity of the TEG among all of the experiments except in the experiment of 8TEG. As it is shown in the graph above, the output of it was increasing with the temperature until it reaches to 200 degrees Celsius. After that, it drops. This is because the reading of thermometer was not that accurate. This is also because the sensor cable was installed in the bottom surface inside the hot box of SIRAJ TEG while the 8 TEGs were installed at the top surface of the hot box. So, the temperature at the bottom surface is not the same as the top surface. For example, if the temperature at the bottom surface is 250 degrees Celsius, the top is going to be less than this value definitely. This is because the heat source is more directed on bottom surface. However, the cable sensor of the thermometer had been installed close to the top surface of SIRAJ TEG. This is to make the reading of the thermometer more accurate and the output more suitable with the temperature difference. However, the temperature that is applied to SIRAJ TEG should not exceed the wanted temperature which 250 degrees Celsius. This is because the thermoelectric generators will burn thus the output will drop.

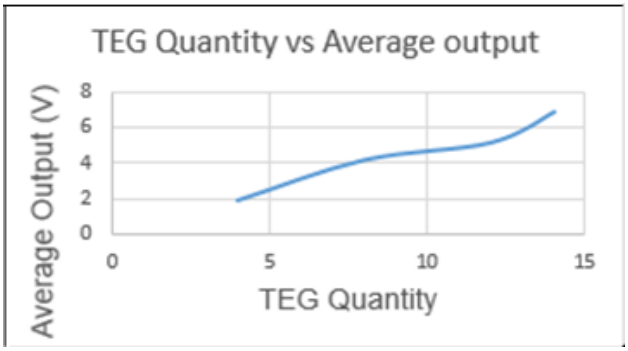

Figure 3: Graph of the TEG Quantity and Average Output (Voltage) for Each Experiment

This graph shows the effectiveness of the TEG quantity on the produced output. As it shown in the graph, as the quantity of TEG is increasing, the output (voltage) is also increasing. For instance, 4 pieces of TEG are producing around 1.8 voltages while for 14 pieces are producing 6.9 voltages. So, the higher the number of the TEG, higher the voltage.

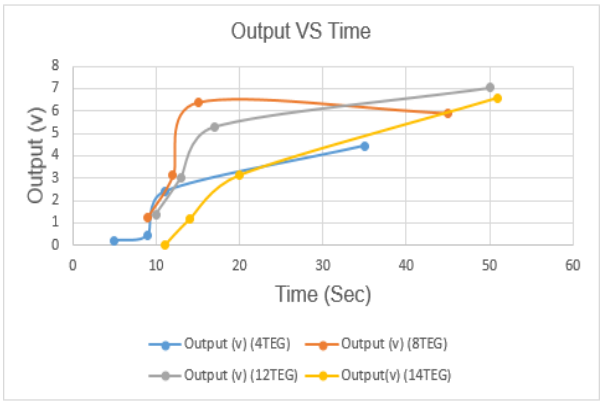

Figure 4: Graph of the Output (Voltage) and the Time for SIRAJ TEG

The graph above clearly shows the relationship between the output and time for the SIRAJTEG. In this graph, the time is playing a big role in effecting on the output of SIRAJ TEG and it is different from an experiment to another. For example, the lowest output of SIRAJ TEG at 5 seconds is around 0.19 voltages. This is recorded during the 4 TEG's experiment and it is considered as the lowest voltage among all of the experiments. However, the highest voltage for this experiment is about 4.43 voltages at 35 seconds. Moreover, the lowest voltage during 8TEG's experiment is 1.26 voltages. This is recorded within 9 seconds. However, for this experiment the voltage drops a little bit to 5.9 voltages at 45 seconds. Thus, the highest value of voltage during this experiment which is 6.39 voltages is recorded at 15 seconds. Besides that, the lowermost voltage for the 12 TEG's experiment which is 1.37 voltages is recorded at a time of 10 seconds while the highest value of voltage which is around 7 voltages is recorded at a time of 50 seconds. In addition, the highest

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value of voltage among all of these experiments which is 9.7 voltages. This value has been recorded during the experiment of 14 TEG's at a time of 51 seconds. As a result, as the time is increasing, the output voltage is also increasing. However, the voltage drops slightly during the 8 TEG's experiment at a time of 45 seconds to 5.9 voltages. And then continue to increase again with time. The drop in voltage with continuous increasing in time is due to the difference in temperature between the hot and the cold section of SIRAJ TEG is not that high. This is because the heat source during this experiment was totally directed to one side which is opposite to the side of where the 8 TEGs were installed.

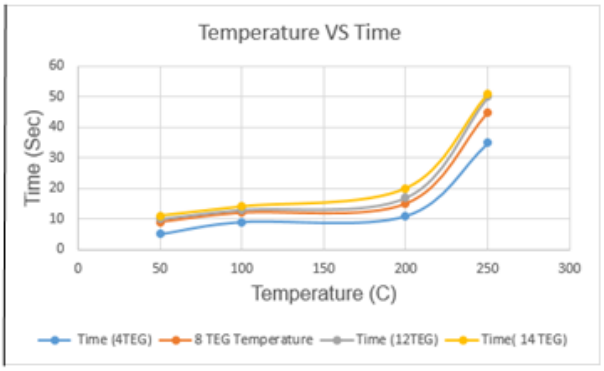

Figure 5: Graph of the Temperature and the Time for SIRAJ TEG

This graph illustrates the temperature and time for SIRAJ TEG. In other words, it studies about the time that is taken for each quantity of TEG to reach to its wanted temperature which is 250 degrees Celsius. Besides that, the temperature has been measure by using a digital thermometer in all of the experiments while the time was measured by using the phone's stopwatch. For instance, 4 TEG are taking about 7 seconds to reach to 50 degrees Celsius and 35 seconds to reach to 250 degrees Celsius. Moreover, 8 TEG are taking around 9 seconds to reach to 50 degrees Celsius and 15 seconds to reach to 200 degrees Celsius. Furthermore, 12 TEG are taking approximately 13 seconds to reach to 50 degrees Celsius and 50 seconds to reach to 250 degrees Celsius. Likewise, 14 TEG are taking nearly 20 seconds to reach to 200 degrees Celsius and 51 seconds to reach to 250 degrees Celsius. As a result, as the temperature of TEG is increasing, the time is increasing as well. This is happening in all of experiments.

4. Conclusion

In this paper, SIRAJ TEG was created successfully by using the difference in temperature phenomenon. This phenomenon worked effectively in generating the needed power for turning on the USB on the A/C by doing different number of experiments by using various number of temperatures.

Acknowledgement

This research was supported by making the experiments at the Universiti Pertahanan Nasional Malaysia (UPNM). The use of the high performance computer in designing the project at the Universiti Kuala Lumpur Malaysian Institute of Aviation Technology (uniKL MIAT) was very appreciated.

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ISSN: 0193 - 4120 Page No. 1997 - 2002

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