UNITECH 2017 GABROVO

INTERNATIONAL SCIENTIFIC CONFERENCE
17-18 November 2017, GABROVO

# INVESTIGATION OF THERMOELECTRIC TECHNOLOGY APPLICATIONS IN AVIATION AND AEROSPACE SYSTEMS

**Hayati Mamur**
*Faculty of Engineering, Manisa Celal Bayar University, 45140, Manisa, Turkey*
*hayati.mamur@cbu.edu.tr*

**Yusuf Coban**
*Faculty of Engineering, Manisa Celal Bayar University, 45140, Manisa, Turkey*

**Abstract**

*With the increase in energy demand, the use of renewable resources in different areas is increasing and their use is encouraged. As in every sector, the need for electrical energy in aviation and space technologies also arises in many areas. To meet this need, electricity is generated in different ways in these technologies. One of the methods of producing electricity is to operate the thermoelectric modules (TEM), which convert the temperature difference between the surfaces into electrical energy on thermoelectric generator (TEG) mode. The power of semiconductor TEGs increases via the temperature difference between the hot and cold surfaces. In addition, TEMs are also used as thermoelectric coolers (TEC) for air conditioning in aviation and aerospace technologies. In this case, an electric power supply is supplied to the running TECs. Depending on the given power, a temperature difference between TEC surfaces occurs. The use of aviation and aerospace systems for the conversion of waste and geothermal temperatures into electrical energy and air conditioning processes increase day by day due to lack of mobile parts, silent running, maintenance free, long lifespan and stable running. In this study, the usage areas and applications of TEMs in aviation and aerospace technologies are examined.*

**Keywords:** Aviation, Aerospace, thermoelectric, thermoelectric module, thermoelectric generator, thermoelectric cooler.

## INTRODUCTION

Thermoelectric energy has always been mentioned in aviation and space systems, which require reliable performance under difficult working conditions. For example, all the power and wireless sensor networks that use their motors heat to monitor their situation are used.

Recent innovations are increasingly taking place in this field as well as in the whole sector. In this study, applications of some aviation and aerospace systems using thermoelectric devices are examined. Sensor and wireless sensor networks have been developed with thermoelectric generators (TEGs) that monitor dangerous structural wear and tear on civil and military aircraft. In the space sector, TEGs are used in satellite and discovery surveillance systems.

## THERMOELECTRIC GENERATOR

Semiconductor materials that convert electrical energy into temperature difference or temperature difference into electrical energy are thermoelectric materials. Bismuth Telluride ($Bi_2Te_3$) is one of the most common and widely used thermoelectric materials [1]. The devices made from these materials are TEGs [2]. Having low efficiency (<10) and being expensive are the biggest disadvantages [3], however, following features are the advantages of a TEGs: having immobile parts, silent running, maintenance free, long lifespan and stable running.

Figure 1 shows the structure and running principle of a TEG. When a temperature difference is created between the TEG surfaces, a voltage difference occurs between the ends of the TEG and the current flows through the load.

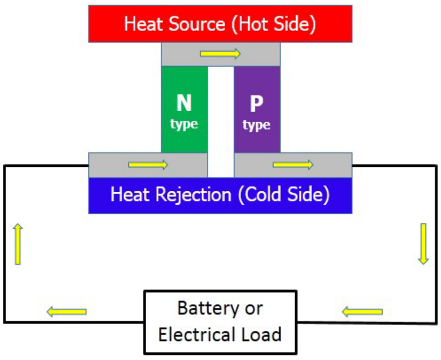
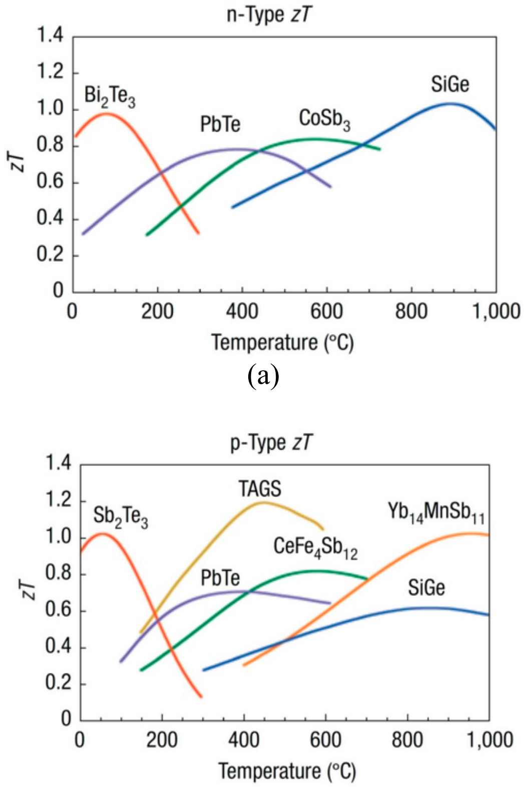


***Fig.1.*** *TEG principle*



(a)

(b)

***Fig.2.*** *Quality factors of thermoelectric materials due to temperature (a) n-type and (b) p-type [5]*

The thermoelectric effect is the direct conversion of the temperature difference into an electrical potential difference or voltage. Thermoelectric effect occurs due to the presence of load carriers in semiconductors, their portability and their ability to carry heat and charge at the same time. To form a thermoelectric pair, two types of thermoelectric material are required: n-type with free electrons and p-type with free holes.

TEGs operate according to the Seebeck effect principle. Temperature difference forms potential difference and this potential difference transforms into electric energy and this is called Seebeck effect. The potential difference $V$ generated from the temperature difference $\Delta T$ [4] and its relation with Seebeck coefficient α is explained by the following equation:

$$V = \alpha \cdot \Delta T \tag{1}$$

where, $\alpha$ is the Seebeck coefficient and its unit V/K.

The figure of merit of a thermoelectric material can be written as:

$$Z = \frac{\alpha^2}{\rho \cdot \lambda} \tag{2}$$

or

$$zT = \frac{\alpha^2 \cdot T}{\rho \cdot \lambda} \tag{3}$$

where, $\rho$ is the resistivity of the material (Ω.m) and $\lambda$ is the conductivity (S). The second equation is only the first equation multiplied by the temperature. Since the materials exhibit different conductivities at different temperatures, the value of Z varies accordingly with temperature. Therefore, for correct comparison, the efficiency is multiplied by $T$.

The quality coefficients of some n- and p-types of thermoelectric materials vary depending on the temperature are given in Figure 2. While $Bi_2Te_3$ n-type thermoelements are used up to about 250°C, SiGe type thermoelements can be used up to 1000°C. The quality coefficients of almost all thermoelements vary from about 0.4 to 1.2, as shown Figure 2(a) and (b) [5].

On the other hand, thermoelectric coolers (TECs) operate according to the Peltier effect principle. This effect is the opposite of the Seebeck effect. In this case, when applying electrical potential difference to the positive and negative terminals of the thermoelements, one of the surfaces of the thermoelements is heated while the other is cooling. Emerging energy (W) is explained as follows:

$$W = \frac{I^2 \cdot (R_a + R_b)}{2} \tag{4}$$

where, $I$ is current (A), $R_a$ and $R_b$ are n- and p-type thermoelement resistance (Ω).

The heating from the square depends on the applied current and the electrical resistances of the thermoelements. Heat conduction depends on the temperature difference and the heat transfer capacities.

While TECs convert electricity energy to Peltier effect temperature, TEGs convert the applied temperature difference to electric power. They work with the opposite logic. This doesn’t mean that every TEC element is used in the form of TEG. While TEGs are designed for energy production, TECs are used for conditioning purposes by creating a temperature difference. Their $zT$ values are different [6]. Figure 3 shows a thermoelectric module (TEM) layout.

***Fig.3.*** *Typical TEM layout (40x40 mm)*

## TEG APPLICATIONS IN AEROSPACE SYSTEMS

Radioisotope thermoelectric generators (RTG) on the basis of nuclear energy have been used in the space industry since the beginning of space exploration with a combination of thermal generators [7]. RTGs do not use nuclear fission or fusion, but use heat from the natural radioactive half-life of plutonium-238 [8]. The first use of the TEG is based on the US Navy's satellite, which was sent in 1961 for discovery and surveillance. This satellite, which was used for over 15 years, produced about 2.7 W of electricity with the SNAP-3 nuclear auxiliary generator (SNAP-3) [9]. RTGs have been used because of their low mass and extreme reliability. They are suitable for remote tasks where solar panels are insufficient to provide energy from sunlight. Voyager I and II spacecraft, which started in 1997, are connected in addition to solar systems due to the high reliability of RTGs. Each spacecraft is equipped with 3 RTGs that deliver about 0.4 kW at about 7 kW. Electricity can provide up to 2020 capacity [10]. In 1997 the Cassini-Huygens spacecraft, jointly sent by NASA and the European Space Agency to study Saturn and its satellites, was also reinforced with three RTGs [11].

## TEG APPLICATIONS IN AIRCRAFT AND HELICOPTERS

The most important purpose in aircraft and helicopter systems is to increase reliability and reduce operating expenses. For this reason, sensors and energy sources placed in places inaccessible to these aircrafts are of great importance. Therefore, it is important to combine energy sources that can be used independently with monitoring and fault detection sensor network systems [12].

An airplane offers numerous temperature differential opportunities to effectively set up TEGs. This can be the temperature difference between the inside and outside of the passenger compartment and the temperature difference between the turbine engine bearings and ambient air [13].

There is a significant amount of heat release from aircraft jet engines and helicopters' turbine engines. A preliminary study by Boeing Research & Technology has shown that 0.5% or more fuel reduction can be achieved with TEG. This means a reduction in fuel costs of US commercial aircraft of 0.5% and operating costs of up to \$12 million per month [14-16]. In a work done, electrical power can be provided with $Bi_2Te_3$ TEG added to the motor nozzles, but this significantly increases the weight of the vehicle [17]. In addition, turboshaft engines used in helicopters and propeller aircraft have heat release in compressor segments, combustion chamber and exhaust outlet. TEGs can be installed in these different zones, contributing to electric energy production. However, care should be taken not to adversely affect the operation of the turbo shaft motor. The important thing to note here is the weight that TEGs bring to air vehicles. Taking into account the power density produced, it is suggested that this weight amount be 0.5 kW/kg [18].

Future roadmap will probably add the weight constraints of the TEG to the design of the aircraft engine or add them to an area with a hot heat flow and a cold heat flow in advance.

New investigations will also contribute to thermoelectric materials. However, it should be noted that the weight of the TEGs must be included in the total weight.

## CONCLUSION

The use of waste heat to generate electrical energy using TEGs appears in a number of applications. The fact that power density is higher than photovoltaic panels in particular makes them attractive in space and aviation sectors. It can reduce fossil fuel consumption and $CO_2$ emissions significantly if it is integrated in the construction of air and space vehicles to reduce its impact on its weight. These robust long-life devices provide reliable and long-term use of the sensors and their associated communication circuits without the need for a battery. Highly environmentally friendly and reliable modules add value, but today they are limited due to their low efficiency and prices.

## REFERENCES

**[1]** Mamur, H. and Bhuiyan, M.R.A. (2017), “Development of Bismuth Telluride nanostructure pellet for thermoelectric applications”, *Istanbul International Conference on Progres in Applied Science 2017 –ICPAS 2017*, pp. 1-5, Istanbul, Turkey.

**[2]** Ahıska, R. and Mamur, H. (2014) “A review: Thermoelectric generators in renewable energy”, *International Journal of Renewable Energy Research*, Vol. 4, No 1, pp. 128-136.

**[3]** Ahiska, R. and Mamur, H. (2016), “Development and application of a new power analyzes system for testing of geothermal thermoelectric generators”, *International Journal of Green Energy*, Vol. 13, No 7, pp. 672- 681.

**[4]** Riffat S.B. and Ma, X. (2003), “Thermoelectrics: a review of present and potential applications”, *Applied Thermal Engineering*, Vol. 23, pp. 913-935.

**[5]** Snyder, G.J. and Toberer, E.S. (2008), “Comply thermoelectric materials”, *Nature Materials*, Vol. 7, pp. 105-114.

**[6]** Mamur, H. and Ahiska, R. (2015), “Application of a DC-DC boost converter with maximum power point tracking for low power thermoelectric generators”, *Energy Conversion and Management*, Vol. 97, pp. 265-272.

**[7]** Champier, D. (2017), “Thermoelectric generators: A review of applications”, *Energy Conversion and Management*, Vol. 140, pp. 167-181.

**[8]** Cataldo, R.L. and Bennett, G.L. (2011), “U.S. Space radioisotope power systems and applications: past, present and future, radioisotopes - applications in physical sciences”.

**[9]** Schwartz, L.I. and Shure, H.J. (1965), “Survey of electric power plants for space applications”, *Fifty-Eight National Meeting of the American Institute of Chemical Engineers*, Philadelphia, Pennsylvania.

**[10]** Voyager, the interstellar mission n.d. <http://voyager.jpl.nasa.gov/spacecraft/index.html> [accessed September 2, 2017]

**[11]** Spacecraft Power for Cassini - NASA fact sheet; 1999.

**[12]** Ancik, Z., et al. (2014), "Simulation modelling of MEMS thermoelectric generator for aircraft applications." *Power Electronics and Motion Control Conference and Exposition (PEMC)*, 16th International. IEEE.

**[13]** DigiKey Electronics <https://www.digikey.com/en/articles/techzone/2014/apr/thermoelectric-energy-generation-takes-flight-for-aircraft-and-spacecraft-monitoring> [accessed June 1, 2017]

**[14]** Brunetti, M., Cogliati, A., Iannucci, D. and Scandroglio A. (2015), “Aircraft capable of hovering having an exhaust duct with thermoelectric conversion circuit”, Google Patents.

**[15]** Brillet, C. (2015), “Thermoelectric generation for a gas türbine”, Google Patents.

**[16]** Kwok, D.W., Huang, J.P., Skorupa, J.A. and Smith, J.W. (2009), “Thermoelectric generation system”, Google Patents.

**[17]** Kousksou, T., Bedecarrats, J-P., Champier, D., Pignolet, P., Brillet, C. (2011), “Numerical study of thermoelectric power generation for an helicopter conical nozzle”, *Journal Power Sources*, Vol. 196, No 8, pp. 4026–4032.

**[18]** Chabas, J., European Commission: CORDIS: Project & Results Service: Final Report Summery – THETAGEN (Thermoelectric for engine control system) n.d. <http://cordis.europa.eu./result/rcn/164433_en.html > [accessed September 8, 2017]