Research, development of the design and calculation of thermal and electrical parameters of the TEG for the ship M/V NSU Keystone

T H Hoang¹ and S V Vinogradov²

¹ Astrakhan State Technical University, Astrakhan, 414056, Russian Federation
² Vietnam Maritime University, 484 Lach Tray, Ngo Quyen, Hai Phong, Vietnam

Abstract. This article is devoted to the issues of increasing the efficiency of thermoelectric generator (TEG) due to the intensification of heat transfer. The analysis of TEG structures and methods for increasing their efficiency are carried out. Based on the analysis, the basic design of the TEG and the method for increasing its efficiency have been selected. The thermal and electrical parameters for the base TEG are calculated using the example of the ship M/V NSU Keystone. A TEG design with changed heat exchanger surfaces from the exhaust gas side of the internal combustion engine has been proposed and changes have been made in the calculation of the thermal and electrical parameters of the TEG taking into account the specific heat exchange processes in the intensified TEG surface.

1. Introduction

The constant rise in prices for liquid petroleum fuel and a shortage of fuel and energy resources is increasing every year. The reason for this is the exhaustion of natural resources. In addition, there are acute questions about environmental safety. One of the ways to solve it in the marine fleet is to increase the economics of ship power plants.

The solutions to this problem is the use of the thermoelectric effect for converting the energy of the heat of exhaust gases from marine diesel engines into electric ones. Thanks to the latest advances in the development of thermoelectric materials and systems, interest in the use of TEG in the grid has been renewed.

Advantages of TEG – significant motor resources, lack of moving parts, quiet operation, ecological purity, versatility with respect to the methods of supply and removal of heat and the possibility of recovering the waste thermal energy.

The disadvantage of TEG is a low efficiency of 1 – 10%. Despite this, thermoelectric generators have found wide application [1].

2. The main characteristics of the ship M/V NSU Keystone and power plant

M/V NSU KEYSTONE is a large deadweight tonnage with 207,684 DWT. This is a big ship of transport company VINIC, which was founded in Vietnam Maritime University, Hai Phong, Vietnam (figure 1). The Japanese manage this company. M/V NSU KEYSTONE has specific parameters and indicates. On the other hand, the Main Engine hardware features such as MITSUI MAN B&W 6S70ME-C8.2, two-
way, one-way, crosshead, exhaust turbocharger (figure 2). It is a modern ship of VINIC Transport Company with the equipment in good condition. Crews in the engine room carefully service them.

Tables 1 and 2 show the parameters and characteristics of the ship as well as the characteristic values of the engine when the vessel is operating at different load modes. Through this, the author wants to calculate and design a device that utilize large amounts of heat loss from the exhaust gas of the main engine to generate electricity, to serve the daily needs of the crew members as well as of the equipment on ship.

**Table 1. Basic technical characteristics of the ship M/V NSU Keystone.**

| No | Parameter            | Value          |
|----|----------------------|----------------|
| 1  | Ship name            | NSU KEYSTONE  |
| 2  | Year of build        | 2013           |
| 3  | Lenght, m            | 290            |
| 4  | Breadth, m           | 50             |
| 5  | Vessel type          | Bulk carrier   |
| 6  | Deadweight, tons     | 207,684        |
| 7  | Gross tonnage, tons  | 107,222        |
| 8  | Ship speeds (knots)  | 17             |

**Table 2. Specifications Engine MITSUI MAN B&W 6S70ME-C8.2.**

| Exhaust system                              | Unit (°C) | Value |
|----------------------------------------------|-----------|-------|
| Temperature after turbocharger, 100% load    | –         | 365   |
| Temperature after turbocharger, 85% load     | –         | 332   |
| Temperature after turbocharger, 75% load     | –         | 313   |
| Temperature after turbocharger, 50% load     | –         | 286   |

**Figure 1.** M/V NSU KEYSTONE. The ship was tested in Saijo, Japan in a weather condition with Main Engine type is MITSUI MAN B&W 6S70ME-C8.2 (19,620 KW x 91 min-1), using fuel oil: Heavy Fuel oil (HFO) at each different load.
3. Development of the construction and calculation of the TEG with the intensified heat exchanger surface for installation after M/E

The design of the TEG was developed for the vessel of the M/V NSU Keystone. Figure 3 forms the TEG model when installed at the aftermath of the boiler with (1) as the boiler, (2) as the thermoelectric generator. The certain calculation objective is on bulk carrier with ship name M/V NSU Keystone due to Nippon Kaiji Kyokai Corporation. The ship can be used to carry bulk cargoes such as iron ore in Australia, Brazil, and USA ... etc.

Figure 2. Main Engine on M/V NSU KEYSTONE (MITSUI MAN B&W 6S70ME-C8.2).

Figure 3. The scheme of installation of TEG after the Boiler.
Figure 4. The structure of the TEG with the intensified surface of the heat exchanger installed after the Boiler.

As shown in figure 4, the main dimensions of the TEG are $L = 5000$ mm, $d = 1600$ mm with the inclination plate included (height is 100 mm, angle is 15 degrees and length is 160 mm). These parameters are simulated on the ANSYS software and provide optimal value. From there, it makes the actual design easier.

4. Methodology for calculating the base version of the TEG for M/V NSU Keystone

The calculation procedure is similar to that specified in [2]; $F_g = \frac{a^2 \sqrt{3}}{2}$, with corrections that take into account the use of inclined plates on the surface of the hot unit. In particular, the calculation of the heat transfer coefficient of gas was changed.

Cross-section area of flue, $m^2$:

$$F_g = \frac{a^2 \sqrt{3}}{2} - F_{ip},$$  

where $a$ – size of the wall face of the hot node, m; $F_{ip}$ – cross-sectional area of inclined plates, $m^2$. 


Cross-sectional area of inclined planes, m$^2$:
\[ F_{ip} = 12h\delta \sin \theta, \quad (2) \]
where $h$ – height of the inclined plane, m; $\delta$ – element thickness, m; $\theta$ – inclination angle.

Clearance between inclined planes, m$^2$:
\[ \delta_b = \frac{L - \delta \cdot N_{ip}}{N_{ip} - 1}, \quad (3) \]
where $L$ – length of the heat exchanger, m; $N_{ip}$ – number of inclined planes in TEG.

Gas rate, m/s:
\[ \omega_g = \frac{G_g}{\delta_b \cdot h \cdot (N_{ip} - 1)}, \quad (4) \]
where $G_g$ – gas consumption, kg/s.

Heat transfer surface area, m$^2$:
\[ F = \frac{Q}{k \cdot \Delta t_{ip}} + F_{sa}, \quad (5) \]
where $F_{sa}$ – plate surface area; $t_{ag}$ – average gas temperature

Reynolds number for gas
\[ \text{Re}_g = \frac{\omega_g \cdot d_{ef}}{v_g}, \quad (6) \]
where $v_g$ – kinematic viscosity of gas, m$^2$/s; $d_{ef}$ – equivalent flue diameter $d_{ef} = \frac{4F_g}{6\pi}$, m.

Exhaust gas of the diesel engine moves in the pipeline in turbulent regime, therefore the Nusselt number for the exhaust gas
\[ Nu_g = 3.25 \text{Re}_g^{0.266} \left( \frac{h}{d_{ef}} \right)^{0.072} \theta^{0.077}, \quad (7) \]
where ($h/d_{ef}$)- ratio height inclined plane with a diameter equivalent flue.

Coefficient of convective heat transfer for gas with augmentation of heat transfer on the surface of a hot unit [3]:
\[ \alpha_g = \frac{Nu_g \cdot \lambda_g}{d_{ef}}, \quad (8) \]
where $\lambda_g$ – coefficient of thermal conductivity of gas, W/(m$^2$ · K).

From the algorithm figure 5 in conjunction with the formula (1)–(8), the authors build a program that calculates the actual power and efficiency TEG when installed on the exhaust pipe of the engine for M/V NSU Keystone. Thus, this technique allows us to determine the geometric parameters of the TEG during their design and the operating parameters for different modes [4].

The figure 6 of the window interface of the program, with each value of input parameters based on the process of work and program "Calculate Automatically TEG" is based on the algorithm loop with the input values are measured parameters of the engine when the ship M/V NSU KEYSTONE journey transporting iron ore from Brazil to Japan. The program makes calculations and graphs in excel format, which helps to evaluate the working process of TEG is easier.
Figure 5. Algorithm for calculating TEG.

Figure 6. Interface for calculating TEG.

5. Results
From the process of entering data, actual measurement on board M/V NSU Keystone combined with algorithms given, program "Calculate Automatically TEG" calculates and displays the data on the form
The values of power, efficiency, voltage and current are expressed in relation to the ratio of load resistance and modules (m).

![Figure 7. Results of calculating the power and efficiency of TEG.](image1)

![Figure 8. Results calculated voltage and current of the TEG.](image2)

The results show the power of TEG when reaching the maximum value of 18 kW and efficiency of 5.2%. From the results of the calculation, the paper launched development-oriented electrical energy source new ships by building a substation phase change from DC to AC-based energy sources by TEG produced. Results achieved makes use of thermoelectric generators in mining activities as well as serving on a ship is more optimal.

6. Conclusion
The article with the target installation solves the problem of increasing the technical and economic indicators TEG by heat transfer enhancement surface.
This paper presents a new thermoelectric generator structure associated with building computer algorithms and programs specific to the electrical parameters of TEG.

Calculations on the program show that the capacity of TEG reached the maximum value of 18,326 kW and the highest efficiency of 5.2%.

Based on the research results and achievements, it will create a premise for the building and development of clean electric energy sources on VINIC's fleets as well as cargo ships in the world.

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