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Effect of the thermal insulation on generator and micro gas turbine system

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ABSTRACT

The efficiency of micro gas turbine generator is affected significantly by the temperature level in the micro gas turbine system. If the operation temperature of generator and compressor increases, the efficiency of generator and compressor decreases, greatly. This study investigates the heat transfer and temperature distribution in a micro gas turbine system. In addition, the temperature levels on the substrates are controlled using the different thermal insulation materials. The thermal conductivity of insulation is changed from 0.1 to 100 to evaluate the effect of the thermal conductivity on generator and micro gas turbine. A conjugate heat transfer method has been used for this purpose. We conducted a CFD analysis in the compressor and turbine flow domains using CFX v.12 to obtain the boundary conditions for conduction calculation. The conduction analysis, using ANSYS v.12, was calculated on the solid part domain. The conduction heat transfer calculation considered the heat generation induced by the Joule heating in the generator. The results show that the most heat flux from the turbine and generator is removed by the inlet flow induced by the compressor. The conductivity of thermal insulation material has a little effect on the temperature distributions of the generator.

1. Introduction

A great deal of research has focused on developing micro gas turbines in the last decade. The goal of these studies is to use the micro gas turbine as the power source of mobile devices, micro robots and military devices, which require high power and high energy density. The micro gas turbine can supply higher power and high energy density than those of a battery or fuel cell. Moreover, the micro gas turbine can supply continuous power; it does not need time to charge, like a battery. Therefore, the development of a micro gas turbine is necessary due to commercialization of high specification mobile devices, micro robots and military devices.

Generally, the micro gas turbine is operated in high rotating speed and high turbine inlet temperature to improve the efficiency. However, these operating conditions of the micro gas turbine induce the high thermal load and it can drop the efficiency of generator and compressor. Especially, as the temperature of the generator and compressor is increased, the total efficiency of the micro gas turbine is steadily decreased [1–3]. Therefore, to prevent decreasing the efficiency of generator and compressor, the design of the micro gas turbine should consider temperature distribution of the substrates and its manipulation.

The micro gas turbine has been exposed on several thermal sources, such as the hot combustion gas and Joule heating in generator. The hot combustion gas is the biggest thermal source in the micro gas turbine. The temperature of hot combustion gas in the micro gas turbine is about 900–1000 °C and the high heat flux transfers from the turbine to the generator and compressor. Verstraete et al. [4] showed the temperature distribution on the substrate of a micro gas turbine which includes the compressor and turbine. They provided accurate values of the temperature on the substrate using a conjugate heat transfer calculating method. That study showed that the temperature of compressor axis was increased due to high heat flux from the turbine. However, that study did not consider heat generation by the Joule heating in the generator, which was another thermal source in the micro gas turbine system.

The heat generations in the generator by the Joule heating are important in the high rotating speed generator because heat generation occurs in the generator and it rises the temperature on the generator, directly. The efficiency of the generator steadily decreases as the temperature increases. In particular, the efficiency of generator

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is decreased significantly, when the temperature of generator is over 200 °C. Despite of the importance of the heat generating by Joule heating, the previous studies did not deal with the heat generations. The most studies usually focused on the high rotating speed and air bearing manufacturing and aerodynamics [5,6].

Recently, in order to enhance the efficiency of micro gas turbine, improve the cooling performance to an actual gas turbine component, heat transfer analysis, thermal analysis, and failure analysis are required [7–9]. Also, some researchers and designers have concentrated on prediction of the temperature distribution on the hot part of the turbine using the CHT (conjugate heat transfer) calculations [10–15]. It helps to enhance the reliability and durability of the hot part of gas turbine. Therefore, predicting the temperature in the micro gas turbine is essential for the micro gas turbine system design to enhance the reliability and durability.

In this sense, the objective of the current study is to predict the heat transfer and temperature distributions considering the various thermal sources in the micro gas turbine system using the conjugate heat transfer calculation. In addition, when the thermal insulation materials are changed, the temperature distributions are compared in each case. To predict the heat transfer and temperature distribution, commercial codes CFX-12 and ANSYS-12 are used to calculate the convection and conduction heat transfer, respectively.

2. Research method

2.1. Structure of the micro gas turbine

Fig. 1 shows the layout of the micro gas turbine. This micro gas turbine is designed for the energy capacity of 500 W. It is composed of a generator, a compressor and a turbine. The generator, compressor and turbine share the axis and are arranged in this order. The generator is located in front of the compressor. The inlet air passes through the passage beside the generator and enters the compressor. The turbine inlet gas comes from the combustion and passes through the guide vane.

The 3D (three-dimensional) radial compressor has seven full blades and seven splitters. 3D radial turbine has eight blades as the components. The guide vane is located in front of the turbine and has fourteen blades. The diameter of the turbine and compressor is 20 mm. The compressor and turbine blade tip clearance is 0.2 mm. The thickness of insulation between the turbine and compressor is 8 mm. The turbine and compressor rotating speed is 400,000 RPM.

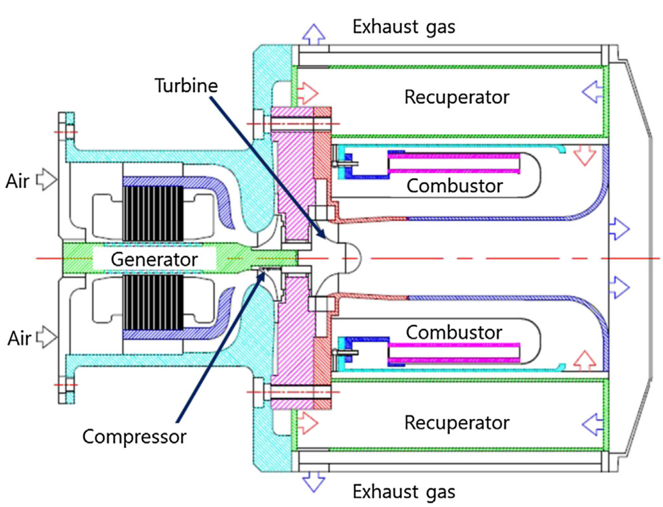

Fig. 1. Layout of micro gas turbine and generator.

The material of the compressor, turbine, turbine shroud and shaft between the compressor and turbine is Inconel 601 ($k = 11.2$ W/m K). The other parts, which include the generator, generator shaft and outside walls, are made of Stainless steel 316 ($k = 21.5$ W/m K). The thermal insulation is located between the turbine and compressor. The different materials are used in the thermal insulation region to estimate the effect of thermal insulation. The thermal conductivity is changed from 0.1 to 100. The dimensions of micro gas turbine are listed in Table 1.

2.2. Thermal resistance in the micro gas turbine

The thermal resistance in the micro gas turbine consists with the conduction and convection, which are shown in Fig. 2. The convective heat transfer induces in the compressor and turbine fluid domains. The convective resistances in the compressor and turbine describes as Eqs. (1) and (2).

$$R_{\mathrm{Conv,C}} = \frac{1}{h_{\mathrm{C}} A_{\mathrm{C}}} \tag{1}$$

$$R_{\mathrm{Conv,T}} = \frac{1}{h_{\mathrm{T}} A_{\mathrm{T}}} \tag{2}$$

The conduction heat transfer occurs in the substrates in the micro gas turbine. As the conduction resistances in the impellers of the compressor and turbine are calculated, these components are considered as a cylinder simply. The conduction resistances in the impeller of compressor and turbine are expressed in Eqs. (3) and (4).

$$R_{\mathrm{Cond,Ci}} = \frac{L_{\mathrm{Ci}}}{k_{\mathrm{Ci}} A_{\mathrm{Ci}}} \tag{3}$$

$$R_{\mathrm{Cond,Ti}} = \frac{L_{\mathrm{Ti}}}{k_{\mathrm{Ti}} A_{\mathrm{Ti}}} \tag{4}$$

The thermal insulation layer is composed with the thermal insulation material and rotating axis. So then, the conduction resistances in the insulation and rotating axis are connected in parallel, which are described as Eq. (5). The total thermal resistance in the micro gas turbine is written as Eq. (6).

$$\frac{1}{R_{\mathrm{Cond,in}}} = \frac{1}{R_{\mathrm{Cond,I}}} + \frac{1}{R_{\mathrm{Cond,a}}} = \frac{1}{\frac{L_{\mathrm{I}}}{k_{\mathrm{I}} A_{\mathrm{I}}}} + \frac{1}{\frac{L_{\mathrm{a}}}{k_{\mathrm{a}} A_{\mathrm{a}}}} \tag{5}$$

$$\begin{aligned} R_{\mathrm{total}} &= R_{\mathrm{Conv,c}} + R_{\mathrm{Cond,ci}} + R_{\mathrm{Cond,in}} + R_{\mathrm{Cond,ti}} + R_{\mathrm{Conv,t}} \\ &= \frac{1}{h_{\mathrm{C}} A_{\mathrm{C}}} + \frac{L_{\mathrm{Ci}}}{k_{\mathrm{Ci}} A_{\mathrm{Ci}}} + \frac{\frac{L_{\mathrm{I}}}{k_{\mathrm{I}} A_{\mathrm{I}}} \frac{L_{\mathrm{a}}}{k_{\mathrm{a}} A_{\mathrm{a}}}}{\frac{L_{\mathrm{I}}}{k_{\mathrm{I}} A_{\mathrm{I}}} + \frac{L_{\mathrm{a}}}{k_{\mathrm{a}} A_{\mathrm{a}}}} + \frac{L_{Ti}}{k_{Ti} A_{Ti}} + \frac{1}{h_T A_T} \end{aligned} \tag{6}$$

2.3. Numerical analysis

To compute the material temperature, the distribution of the adiabatic wall heat transfer coefficients primarily need. The present study is based on a numerical analysis of the flow and

Table 1
Dimensions of micro gas turbine.

Diameter of turbine and compressor	20 mm
Tip clearance in the turbine and compressor	0.20 mm
Length of shaft between turbine to compressor	8.0 mm
Length of generator shaft	45 mm