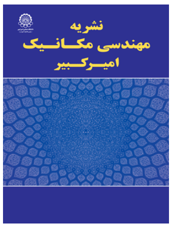

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Numerical Analysis of the Effect of Natural Convection Heat Transfer on the Gas Turbine Axial Compressor Casing

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ABSTRACT: The distortion of the turbine casing in response to changes in pressure and temperature conditions takes place due to various reasons. Casing distortion decreases the efficiency by increasing the flow loss at the tip of blades and seals of the turbine. In this study, the effect of natural convection heat transfer on the compressor's casing in gas turbine was investigated. For this purpose, the fluid and solid domains were simultaneously and transiently analyzed by numerical method while applying different boundary conditions to a two-dimensional model. The results showed that due to natural convection, the temperature of the upper parts of the casing increased up to a certain time and then faced a fluctuating decrease, while the temperature of the lower parts generally decreases over time. Natural convection causes a considerable temperature difference in the casing at shutdown conditions. Also, flow turbulence in the fluid is high due to the high Rayleigh Number. Although the Rayleigh Number increases as the environment's convection transfer coefficient raises, the temperature gradient between the upper and lower casing decreases locally. To reduce the casing distortion, practical solutions of adjusting the environment's convection transfer coefficient, changing the logic of bleed valves, and improving casing insulation have been proposed.

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1- Introduction

One of the serious problems in power generation plants is casing distortion, which may damage the turbine components [1]. One of the conditions causes the temperature gradient in the casing is the turbine shutdown mode. On the other hand, the critical situations at engine shutdown, for the casing, shaft and consequently the entire engine, is stopping shaft at once for any reason without barring round. In this case, due to the lack of mass flow, there is natural convection between the shaft and the casing. At the shutdown mode, it is anticipated that one of the factors causing a temperature gradient in the casing is the natural convection. Here, it is necessary to determine the temperature gradient generated solely by the natural convection heat transfer in the casing. If the generated gradient is significant, it can be concluded that natural convection is one of the major factors in casing distortion. Therefore, in this paper, the temperature gradient generated in the casing from the standpoint of the natural convection heat transfer at shutdown mode has been investigated using numerical methods in the ANSYS CFX 16 software.

2- Methodology

2- 1- Modeling

In this study, a cross-sectional compressor casing of a gas turbine is modeled with dimensional and applied realistic boundary conditions. For this purpose, a part of the inner and outer casing, with the shaft and the fluid between them, are modeled as concentric cylinders. In this case, due to the fact that the flow rate only exists in the early stages of the shutdown and is very low, the flow rate in the axial direction is neglected. In Fig 1, the geometry of the two-dimensional model is shown. Since the geometry and applied boundary conditions are quite symmetrical to the vertical axis, half of the geometry is modeled to accelerate the process of solution.

In order to achieve the heat distribution of the structure, it is necessary to solve the energy transfer (convection) equation in the fluid and its effect on the solid temperature should be taken into account. One of the most accurate methods is the conjugate heat transfer analysis. That is, the heat transfer equation is solved simultaneously in two solid and fluid domains, with the difference that the momentum equation is not solved in the solid domain. In this study, the turbulence model of has been used. This turbulence model has high accuracy in modeling the flow both near the wall and in flow away from the wall.

In this analysis, a model without the shaft is simulated to solve steady state. Under these conditions, the constant temperature has been applied to the internal wall of the main gas. The results of solving steady mode are used as the initial condition for the main model (model with shaft). Since the process of shutting down and starting the natural convection between the components is transient, the original model is solved transiently. To solve this problem, three boundary conditions are applied to the outer casing, which are given in Table 1.

2- 2- Validation

To ensure the accuracy of the numerical solution of the present

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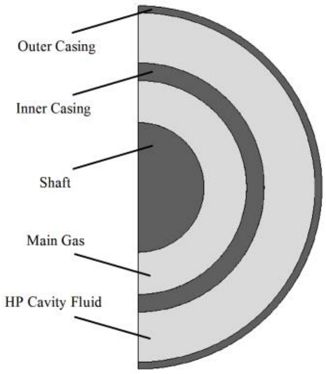

Fig. 1. Hybrid turbine model

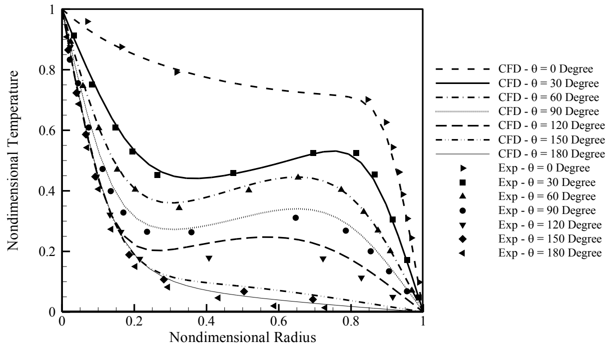

Fig. 2. The flow field and boundary conditions

Table 1. Turbine characteristics

Case	Temperature (°C)	Convection heat transfer coefficient (W/m^2 K)
1	30	10
2	30	30
3	30-50	10

study, a model is simulated based on the experimental results of Kuehn and Goldstein [2]. Fig. 2 shows the dimensionless temperature in terms of the dimensionless radius in several different angles for experimental results [2] and the numerical results of the present study. Angles 0 and 180 degrees represent the uppermost and lowermost points of the casing, respectively. As it is clear from Fig. 2, the results of the numerical study are in good agreement with the experimental data.

3- Results and Discussion

As a result of natural heat transfer, the temperature of the upper points of the casing increases to a specific time and then goes through a fluctuating decrease, while the temperature of the lower points of the casing generally decreases. In the first model, after about 4 hours, the temperature difference between the upper and lower casing reaches about 24°C, which is a significant amount. The presence of this temperature gradient causes significant distortion in the turbine casing. Due to the connection between inner and outer casings, the tip clearances is increased which increases the loss at the blade tips and seals of the turbine, decreasing the efficiency. One of the proposed solutions is changing the logic of compressor's bleed valves at shutdown [3].

To illustrate the effect of the heat transfer coefficient on the temperature gradient of the casing, the second model is analyzed. In this model, the heat transfer coefficient of the environment is tripled compared to the first model. After about 5 hours, the temperature difference reaches a maximum of 14°C. Thus, by increasing the heat transfer coefficient, the temperature gradient, in this case, is lower than the first model by about 10°C that is significant compared to the first model. Therefore, increasing the convection heat transfer coefficient on the outer casing can be a suitable solution for reducing the temperature gradient. For this purpose, one of the methods is to use a blower for air conditioning inside the enclosure to control the heat transfer coefficient. In this case, due to the creation of forced convection around the upper casing, the temperature of the upper part of the casing is reduced and the temperature difference with the lower part decreases.

In the third model, it is assumed that the ambient temperature around of outer casing varies linearly from 30°C at a lower part to 50°C at the upper part of the casing. After 6 hours, the temperature difference reaches about 38°C. In this case, the temperature difference in the casing is about 14°C more than the first model, which is a significant amount. This result indicates the importance of proper casing insulation to minimize the effect of the environment temperature gradient around the casing. The turbine casing may have a temperature gradient due to the insufficient thermal insulation of the casing or weak insulation in the other locations. The cause of the thermal insulation loss can be poor insulation in the connections between joints and pipes to the casing, especially in the lower area of the turbine. Therefore, casing insulation should be done accurately, especially in more sensitive areas.

4- Conclusions

The hydrodynamic analysis of the fluid showed that Rayleigh Number, which has a decreasing trend over time, is high in terms of quantity. According to the high value of Rayleigh Number, streamlines of fluid indicated high flow turbulence. In the main gas of the compressor and the fluid of the high-pressure cavity, several vortices were generated overtimes which were displaced due to fluid's circulatory flow caused by the temperature difference of the surfaces.

This study was analyzed by applying different boundary conditions in three models. The results showed that in the first model, the temperature gradient between the upper and lower points of the casing was about 24°C. To reduce the temperature gradient in these conditions, changing the logic of bleed valves was proposed. In the second model, with an increase in the convection heat transfer coefficient, a significant reduction of 10°C was observed in the temperature gradient of the outer casing. To create this situation in the turbine enclosure, the use of air conditioning was proposed to control and adjust the forced convection heat transfer coefficient of the environment. In the third model, a temperature gradient was applied to the temperature of the environment around the outer casing with the same heat transfer coefficient of the first model. Here, the highest degree of temperature gradient of the outer casing was about 38°C. In this model, improving the casing insulation, especially in more sensitive locations such as joints, was presented as a solution. In all three models, the upper part of the outer casing begins to experience a rise in temperature until a specific time and then begins to cool down at a low rate, while the temperature of the lower casing generally had a decreasing trend. Depending on the thermal interaction of the casing and the surrounding fluid, natural convection on its own caused a significant temperature gradient in the casing.

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