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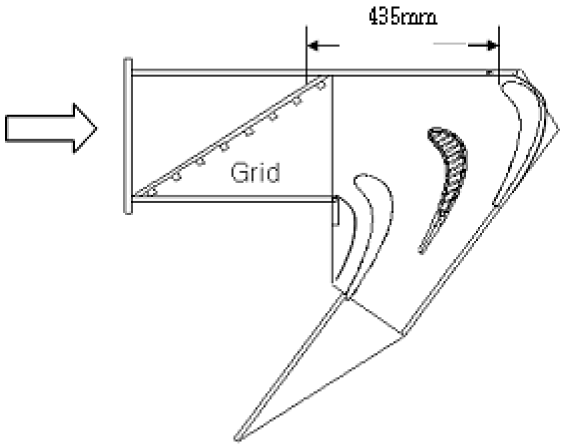
HEAT TRANSFER CHARACTERISTICS ON TIP AND INNER RIM SURFACES OF ROTOR BLADE WITH SQUEALER RIM

Jun Su Park[1], Dong Hyun Lee[1], Woo Jin Lee[1], Hyung Hee Cho[1,*],
Dong-Ho Rhee[2], and Shin-Hyung Kang[3]

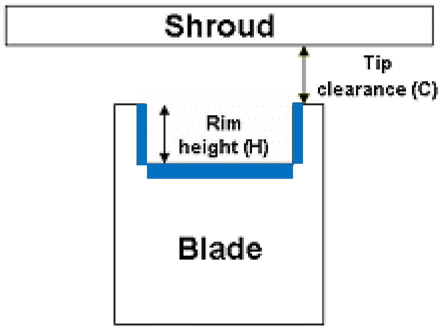
[1] School of Mechanical Engineering
Yonsei University, Seoul 120-749 Korea
[2]Korea Aerospace Research Institute
Daejeon, 305-333, Korea
[3]School of Mechanical and Aerospace Engineering
Seoul National University, Seoul, 151-744, Korea
([*] Corresponding author: hhcho@yonsei.ac.kr)

The tips of gas turbine rotor blade experience large thermal loads, which can lead to tip damage. The large thermal loads on the tips of rotor blade are due to the hot leakage flow through the gap between rotating blade tip and stationary shroud. The hot leakage flow accelerates due to the large pressure difference between the pressure and suction sides of blade, resulting a thin boundary layer and high heat transfer rates. The flow across the blade tip is also undesirable from the perspective of efficiency since it increases the loss of turbine power. For this reason, squlealer-type tip is used to reduce the leakage flow. Rim and groove increase the flow resistance of the leakage flow, resulting decrease of the leakage flow rate. However, the thermal loads and stresses are concentrated in the tip edge of rotor blade and occur crack and breakage. Therefore, it is very important to understand the heat transfer characteristics on surfaces inside the cavity of the squealer tip, such as tip surface and inner rim surface. Kwak et al.[1] measured detailed heat transfer coefficients on the squealer tip compare with flat tip. Tips with single/double rim type were studied at the pressure side, suction side, camber line using transient liquid crystals technique (TLC). Goldstein et al.[2] studied about heat transfer coefficients on the squealer tip with winglet type rim on pressure side and compared with general squealer tip using naphthalene sublimation method. Bunker et al.[3] investigated the detailed distribution of convective heat transfer coefficients on the first-stage blade tip surface in the stationary blade cascade. Rhee et al.[4] studied heat transfer characteristics on the blade tip surface using the naphthalene sublimation method.

The present study inverstigates detatiled heat transfer distribution of gas turbine tip and inner rim surfaces with various rib heights and tip clearances. The experimental apparatus is equipped with the linear cascade of three blades. Figure 1 shows overall layout of the test section. An open type wind tunnel is connected on the front of the test duct and the entrance size of duct is 300 mm × 198 mm. Turbulent grid is set at 435 mm from the center blade in the cascade. The bar width and mesh size of the grid is 9 mm and 52 mm, respectively, thus porosity of the grid is 0.684. Using such grid, the turbulence intensity is approximately 12% at 150 mm from the leading edge of center blade and the velocity of the mainstream is about 11.8 m/s. Each blade is manufactured based on an actual blade tip profile with an enlarged scale. The blade axial chord length (C_x), pitch (p), span (s) and turning angle are 237 mm, 213 mm, 200 mm and 126°, respectively. The test blade positioned at the center consists of a base blade and 3 test plates for naphthalene casting.



(a) Linear cascade



(b) Rim height and tip clearance

Fig. 1 Schematic views of experimental apparatus

Naphthalene sublimation method is used to measure detailed local transfer coefficient on the surface. The three surfaces inside the cavity of blade tip, such as the tip surface, inside rim surfaces on pressure and suction sides, are coated with naphthalene except the circumferential edges of measuring regions for reference points, as shown in Fig. 1(b). Tip clearances and rim heights are selected 1%, 2%, 3% and 3%, 6%, 9% of the axial chord length, respectively. To obtain the local heat/mass transfer coefficient, local sublimation depth of naphthalene is measured on the test surfaces using LVDT.

The Sherwood number, a non-dimensional form of mass transfer coefficient, is calculated by;

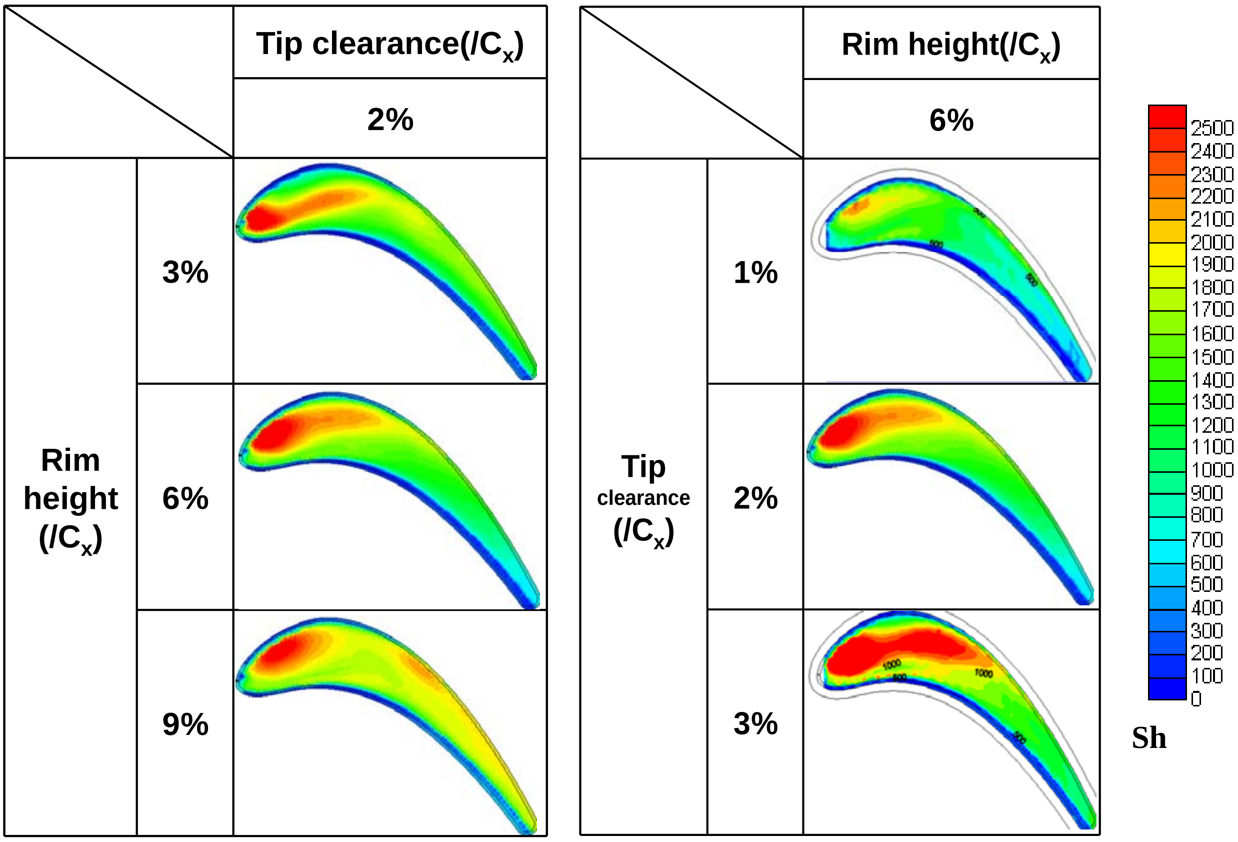
$$\mathrm{Sh} = h_m D_h / D \qquad (2)$$

Where D is calculated from a correlation equation suggested by Goldstein and Cho[5]. Mass transfer coefficient can be converted to the heat transfer coefficient using the heat and mass transfer analogy as shown in Eq. (3)

$$\mathrm{Nu/Sh} = (\mathrm{Pr/Sc})^n \qquad (3)$$

Figure 2(a) presents contour plots of the Sherwood numbers on the tip surface for various rim heights at 2% tip clearance. High heat transfer regions are shown near the leading edge and the Sherwood number decreases rapidly as moving to the downstream region. As the rim height increases, the peak values moves to the suction side edge. This pattern is formed by the reattachment of tip leakage flow. The leakage flow over the pressure side rim impinges on the tip surface near the leading edge region. The leakage flow forms a recirculating flow inside the tip cavity and moves along the suction side rim. Thus, high heat transfer region appears near the suction side corner on the downstream region. The high heat transfer region is enlarged as the rim height increases, as shown Fig. 2(a).

Figure 2(b) shows contour plots of the Sherwood numbers on the tip surface for various tip clearances at 6% rim height. The amount of leakage flow also increases, as the tip clearance increases. Therefore, the value and region of high heat/mass transfer increase near the leading edge with increasing the tip clearance. Thus, the high tip clearance should be avoided to reduce thermal damage as well as loss of turbine efficiency.



(a) Changed the rim heights (b) Changed the tip clearance

Fig. 2 Contour plots of Sh on Tip Surfaces

CONCLUSION

In this study, local heat transfer distributions were measured inside the surfaces of tip cavity with various rim heights and tip clearances. High heat transfer coefficients are observed near the leading edge region by reattachment of the tip leakage flow. As the rim height increases, the high heat transfer region formed by impingement of leakage flow moves away from the leading edge region and the peak heat transfer coefficient decreases slightly. The value and region of high heat/mass transfer coefficients increase significantly near the leading edge with increasing the tip clearance.

REFERENCES

[1] Kwak, J.S., Ahn, J., Han, J.C., Lee, C.P., Bunker, R.S., Boyle, R., Gaugler, R., 2003, "Heat transfer coefficients on the squealer tip and near-tip regions of a gas turbine blade with single or double squealer", J. Turbomachinery, Vol. 125, pp. 778-787.
[2] Papa, M. Goldstein, R.J., Gori, F., 2003, "Effects of tip geometry and tip clearance on the mass/heat transfer from a large-scale gas turbine blade", J. Turbomachinery, Vol. 126, pp. 110-121.
[3] Ronald S. Bunker, Jeremy C. Bailey, Ali A. Ameri, 2000, "Heat transfer and flow on the first-stage blade tip of a power generation gas turbine: Part 1 - Experimental results", J. Turbomachinery, Vol. 122, pp. 263-271.

[4] Dong-Ho Rhee, Hyung Hee Cho, "Local Heat/Mass Transfer characteristics on a Rotating Blade With Flat Tip in Low-Speed Annular Cascade-Part II : Tip and Shroud", ASME J. of Turbomachinery, Vol. 123 (2006) pp. 110-119.
[5] Goldstein, R. J., Cho, H. H., 1995, "A review of mass transfer measurement using naphthalene sublimation", Experimental Thermal and Fluid Science, Vol. 10, pp. 416-434.