Numerical Study on Flow and Heat Transfer Characteristics of Radial Rim Seal Pre-swirl Disk Cavity Postprint

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Abstract

This paper investigates the flow and heat transfer characteristics in a pre-swirl cavity with radial rim seal by solving the RANS equations using the SST turbulence model, and studies the sealing performance of the radial seal employing the additional variable method. Comparisons are made of the cavity discharge coefficient, disc surface Nusselt number, and sealing effectiveness under various coolant flow rates and inlet pre-swirl ratios. The results indicate that at the mid-plane, the pre-swirl ratio increases with increasing inlet pre-swirl ratio, while the static pressure coefficient increases linearly in the radial direction. Mainstream ingestion elevates the adiabatic temperature of the disc wall, and the Nu calculated from the flow condition is slightly overpredicted compared to the actual value. Inlet pre-swirl enhances the sealing effectiveness.

Full Text

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Numerical Investigations of the Flow and Heat Transfer in a Pre-swirl Rotor-Stator Cavity With Rim Radial Seal

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Abstract The flow and heat transfer characteristics in a pre-swirl rotor-stator cavity with rim radial seal are numerically investigated using RANS equations and the SST turbulence model. An additional passive tracer method is employed to simulate mainstream ingestion phenomena. The study examines variations of the flow coefficient in the cavity, the Nusselt number on the rotor surface, and sealing efficiency under different sealing flow rates and pre-swirl ratios. Numerical results demonstrate that within the cavity, the pre-swirl ratio increases with the inlet pre-swirl ratio. The static pressure coefficient increases linearly along the radial direction. Due to mainstream ingestion causing a rise in the rotor' s adiabatic temperature, the Nusselt number calculated based on the flow state is slightly larger than the actual value. Inlet pre-swirl is beneficial for improving sealing efficiency.

Keywords: turbine; rim seal; pre-swirl system; numerical simulation

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2.3 Analysis of Flow and Heat Transfer Characteristics

The Nusselt number is defined as $Nu = hr/k = q_w r/[k(T_w - T_{w,ad})]$, where $T_{w,ad}$ represents the adiabatic wall temperature. The adiabatic temperature on the rotor surface is calculated using the equation:

$$T_{w,ad} = T_{0,p} - \frac{\Omega^2 r^2}{2c_p}\left(1 - \frac{v'_{,1}}{\Omega r}\right)^2$$

where $v'_{,1}$ denotes the pre-swirl velocity at the inlet ($Pr^{1/3}$). Figure 8 [Figure 8: see original paper] illustrates the radial variation of the Nusselt number on the rotor surface for different flow coefficients. The results indicate that mainstream ingestion leads to an increase in the adiabatic temperature on the rotor, causing the calculated Nusselt number to be slightly higher than the actual value.

Figure 9 [Figure 9: see original paper] shows the distribution of adiabatic temperature on the rotor surface. The effect of sealing flow rate on sealing efficiency is presented in Figure 10 [Figure 10: see original paper], which reveals that higher sealing flow rates generally improve sealing performance. The circumferential distribution of static pressure coefficient in the annulus is depicted in Figure 11 [Figure 11: see original paper], demonstrating periodic variations corresponding to the stator vanes.

The distribution of radial velocity in the axial clearance is shown in Figure 12 [Figure 12: see original paper], while Figure 13 [Figure 13: see original paper] displays the sealing efficiency at different radial positions. These results are obtained for flow coefficients of $C_w = 1500$ and $C_w = 6000$, representing different operating conditions. The static pressure coefficient exhibits a linear increase along the radial direction, consistent with theoretical expectations for rotating cavity flows.

The numerical simulations employ the SST turbulence model to capture the complex flow phenomena in the pre-swirl system. The passive tracer method effectively simulates mainstream ingestion, which is critical for accurately predicting sealing efficiency and thermal performance. The study demonstrates that inlet pre-swirl significantly influences the flow structure and heat transfer characteristics within the cavity, with higher pre-swirl ratios generally enhancing sealing effectiveness.

References [1] Patinios M, Scobie J A, Sangan A M, et al. Measurements and Modelling of Ingress in a New 1.5-Stage Turbine Research Facility [R]. ASME Paper GT2016-57163, 2016.

[2] Sangan C M, Pountney O J, Zhou K Y, et al. Experimental Measurements of Ingestion Through Turbine Rim Seals-Part I: Externally Induced Ingress [J]. ASME Journal of Turbomachinery, 2013, 135(2): 319-329.

[3] Sangan C M, Pountney O J, Zhou K Y, et al. Experimental Measurements of Ingestion Through Turbine Rim Seals-Part II: Rotationally Induced Ingress [J]. ASME Journal of Turbomachinery, 2013, 135(2): 319-329.

[4] Sangan C M, Pountney O J, Scobie J A, et al. Experimental Measurements of Ingestion Through Turbine Rim Seals-Part III: Single and Double Seals [J]. ASME Journal of Turbomachinery, 2013, 135(5): 1790-1791.

[5] Beard P A, Chew J, Gao F, et al. Unsteady Flow Phenomena in Turbine Rim Seals [R]. ASME Paper GT2016-56110, 2016.

[6] Savov S S, Atkins N R, Uchida S. Comparison of Single and Double Lip Rim Seal Geometry [R]. ASME Paper GT2016-56317, 2016.

[7] Liu G, Wu H, Feng Q, et al. Theoretical and Numerical Analysis on the Temperature Drop and Power Consumption of a Pre-swirl System [R]. ASME Paper GT2016-56742, 2016.

[8] Zhang F, Wang X, Li J. Numerical Investigation of Flow and Heat Transfer Characteristics in Radial Pre-Swirl System with Different Pre-Swirl Nozzle Angles [J]. International Journal of Heat and Mass Transfer, 2016, 95: 984-995.

[9] Zhang F, Wang X, Liao G, et al. Computational Fluid Dynamics Analysis for Effect of Length to Diameter Ratio of Nozzles on Performance of Pre-Swirl Systems [J]. Proceedings of the Institution of Mechanical Engineers Part A-Journal of Power and Energy, 2015, 229(4): 381-392.

[10] Tao Z, Zhang D, Luo X, et al. Windage Heating in a Shrouded Rotor-Stator System [J]. ASME Journal of Engineering for Gas Turbines and Power, 2014, 136(6): 0626021-6260210.

[11] Luo X, Wang L, Zhao X, et al. Experimental Investigation of Heat Transfer in a Rotor-Stator Cavity with Cooling Air Inlet at Low Radius [J]. International Journal of Heat and Mass Transfer, 2014, 76: 65-80.

[12] Owen J M, Wu K, Scobie J A, et al. Use of Pressure Measurements to Determine Effectiveness of Turbine Rim Seals [J]. ASME Journal of Engineering for Gas Turbines and Power, 2015, 137(3): V05CT16A004.

[13] Lalwani Y, Sangan C M, Wilson M, et al. Steady Computations of Ingress Through Gas Turbine Rim Seals [J]. Proc. IMechE Part A: Journal of Power and Energy, 2015, 229(1): 2-15.

[14] Scobie J A, Sangan C M, Owen J M, et al. Experimental Measurements of Hot Gas Ingestion Through Turbine Rim Seals at Off-Design Conditions [J]. Proc. IMechE Part A: Journal of Power and Energy, 2014, 228(5): 491-507.

[15] Gao Qin, Li Jun. Numerical Investigations for Sealing Efficiency of the Turbine Rim Radial Seal [J]. Journal of Xi' an Jiaotong University, 2014, 48(9): 55-61.

[16] Karabay H, Wilson M, Owen J M. Predictions of Effect of Swirl on Flow and Heat Transfer in a Rotating Cavity [J]. International Journal of Heat and Fluid Flow, 2001, 22(2): 143-155.

Note: Figure translations are in progress. See original paper for figures.