AN EXPERIMENTAL INVESTIGATION ON TRANSPIRATION COOLING

Von der Fakultät Energietechnik der Universität Stuttgart
zur Erlangung der Würde eines Doktor-Ingenieurs (Dr.-Ing.)
genehmigte Abhandlung

vorgelegt von
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Mitberichter: Prof. Dr.-Ing. E. Laurien
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PREFACE

I am from the University of Science and Technology of China in the People's Republic China Hefei, and from 1998 April to 1999 April was supported by China Scholarship Council to attend in an advanced education at the Institut für Thermische Strömungsmaschinen und Maschinenlaboratorium (ITSM) of the University Stuttgart. In this period I have started an interesting work - an experimental investigation on transpiration cooling under the guiding of Professor Stetter. From 1999 July to 2002 March, this investigation was supported by of the ITSM.

Transpiration cooling using porous material to mantle gas turbine blades is a relatively novel concept. All experiments were conducted in the hot gas wind tunnel at the ITSM of the University Stuttgart. These experiments present a quantitative comparison between transpiration cooling and film cooling. The aim of this experimental investigation is to provide a comprehensive reference for the researchers and designers of gas turbine cooling systems to choose a cooling method and medium, and to achieve a better cooling effect.

In this experimental investigation I have obtained the helpful guidance and encouragement from the leaders of the ITSM, Professor Dr.-Ing. Stetter, Dr.-Ing Messner, useful suggestions from Professor Dr.-Ing. Goede and Professor Dr.-Ing. Laurien, and assistant from a number of my colleagues. I would like to express my appreciation for the excellent cooperation.

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Jianhau Wang

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NOMENCLATURE

A	area
c_p	specific heat at constant pressure
C_p	pressure coefficient, relative pressure
C_T	relative temperature
C_D	drag coefficient
D	diameter
f	factor ≤ 1
G	gray scale level
h	enthalpy
Nu	Nusselt number
P	pressure
q	heat
Re	Reynolds number
T	temperature
v	velocity
w	work
x, y, z	Cartesian coordinate

Greek symbols

η	efficiency or cooling effectiveness
κ	specific heat ratio
ϕ	view angle
θ	orientation angle
Δ	difference
ρ	density

Subscripts

1,2,3,4,5,i	at different position
comp	compressor
turb	turbine
net	net
th	thermocouple
ir	infrared
cw	cooled wall
in	inlet, initial wall
c	coolant
∞	free stream
avg	average
loc	local
e	emissivity
w	window
p	position

ABSTRACT

Porous transpiration cooling is a novel theme in the investigation of gas turbine cooling techniques. In order to conduct feasibility experiment and fundamental investigations, a hot gas wind tunnel and the corresponding coolant supply system were designed and built in the Institute of Thermal Turbomachinery at the University of Stuttgart. Infrared thermal imaging techniques appeared to be the most effective method to measure and evaluate transpiration cooling performance. The influence of this technique on measurement accuracy was analyzed and the corresponding calibration method was discussed and used. In further tests, two circular tubes were used as specimens. One tube was made of sintered porous material with a porosity of 21% to create a transpiration cooling effect, the other tube consisted of solid material with four rows of discrete injection holes to simulate the film cooling effect in different regions, namely in the two stagnation regions and on the side of turbine blades. This report presents the results of five comparative experiments. The first experiment found that when a gaseous medium was used as a coolant, transpiration cooling in the leading stagnation region and on the side of the specimen was more effective than film cooling; whereas in the trailing region, the traditional film hole injection cooling method may be more suitable than porous transpiration cooling, especially for the turbine blades with narrow trailing edges. The second experiment demonstrated that the water evaporation cooling effect on the porous surface was much higher and the corresponding coolant coverage was much larger than on the solid surface in the two stagnation regions and on the side of the specimens. In the third experiment, gaseous and liquid coolant were used as transpiration cooling media separately, this experiment showed that the coverage of the two cooling media was almost identical, except that liquid evaporation cooling in the leading and trailing stagnation regions was more effective than gaseous cooling. This was an important discovery that may be used to solve the stagnation region problems in turbine blade cooling. The fourth comparative experiment showed that when the upstream state was changed, porous transpiration cooling had greater stability than solid film cooling. This was another advantage of transpiration cooling over film cooling. The last experiment compared the influence of various coolant injection methods on the mainstream field. The comparison proved that coolant injection from the film holes at the leading line and on the side of the solid tube resulted in a relatively large change in the wall static pressure of the wind tunnel downstream of the injection holes, whereas coolant injection from the pores in trailing region led to a large wall static pressure change upstream of the specimen. These comparative experiments indicate that porous transpiration cooling is a very promising method for gas turbine cooling.