MODELING STUDY OF A GAS TURBINE BURNER COOLING RING EFFICIENCY IN A MODEL COMBUSTOR EXIT DUCT

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PENGESAHAN PENYELIA

“ Saya akui bahawa saya telah membaca
karya ini dan pada pandangan saya karya ini
adalah memadai dari segi skop dan kualiti untuk tujuan penganugerahan
Ijazah Sarjana Muda Kejuruteraan Mekanikal (Automotif)”

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Laporan ini dikemukakan sebagai

memenuhi syarat sebahagian daripada syarat penganugerahan

Ijazah Sarjana Muda Kejuruteraan Mekanikal (Automotif)

Fakulti Kejuruteraan Mekanikal

Universiti Teknikal Malaysia Melaka

MEI 2010

"I hereby to declare that this project report entitled MODELING STUDY OF A GAS TURBINE BURNER COOLING RING EFFICIENCY IN A MODEL COMBUSTOR EXIT DUCT is written by me and is my own effort except the ideas and summaries which I have clarified sources"

Signature : ……………….………………
Author : SUHAILA BINTI MAT SAID
Date : MAY 2010

"Dedicated to my lovely parents, family, friends and lecturers who has been supportive and give encouragement throughout my whole life"

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ABSTRACT

The main purpose of this study is to increase the efficiency of gas turbine burner cooling ring in a model combustor exit duct. The Computational Fluid Dynamics (CFD) package of FLUENT will use to simulate 2D cooling ring model. The modeling of burner cooling ring is taken under turbulence models of two equation model, which are turbulent kinetic energy, k and the energy dissipation, ε or known as standard *k-epsilon* model. The cooling ring effectiveness is dependent upon the approach flow turbulence; the temperature; velocity distribution; and the blade and cooling ring geometry. The 2D geometry of a gas turbine cooling ring is built up with suitable grid to determine the heat coefficient and its effectiveness. There are 3 cases during this study; the cooling ring efficiency is investigated at fixed velocity of 10 m/s and the turbulence intensity, α between 5% to 25%, and the other one is at fixed turbulence intensity, α of 10% and varies the value of velocity between 5 m/s to 25 m/s. The third case is by varies the size of cool air inlet for 10 mm to 40 mm. Both temperature, T at cool air inlet and hot air inlet is constant at 293 K and 1000 K respectively. In this study the wall is assumed to be solid wall with adiabatic wall temperature and non-slip boundary condition. Both pressure inlet and outlet are same. After simulate using CFD, the graph of cooling ring performance will be obtained. As the result, the most cooling effectiveness will increase with increasing velocity, decreasing turbulence intensity, with large size of coolant air inlet.

ABSTRAK

Tujuan utama kajian ini adalah bagi meningkatkan kecekapan salur pendingin di saluran keluar pembakar pada turbin gas. Simulasi CFD yang menggunakan pakej FLUENT digunapakai untuk mensimulasikan model salur pendingin dalam model 2D. *k-epsilon* model telah dipilih untuk digunakan bagi tujuan mensimulasikan model 2D salur pendingin ini. Keberkesanan salur pendingin ini adalah bergantung pada aliran pendekatan *turbulent* iaitu suhu, pengedaran kelajuan, dan geometri salur pendingin. Grid yang bersesuaian digunakan pada model 2D salur pendingin agar data yang diperolehi lebih tepat. Terdapat 3 kes bagi projek ini, dimana yang pertama, kecekapan salur pendingin pada salur penyejuk ditentukan dengan memalarkan kelajuan pada 10 m/s dan mengubah *turbulence intensity,* α pada 5% hingga 20%. Manakala bagi kes kedua pula, *turbulence intensity* dimalarkan pada 10% dan kelajuannya diubah dari 5 m/s hingga 25 m/s. Bagi kes yang terakhir, saiz salur pendingin ditukar dari 10 mm hingga 40 mm. Kelajuan dan *turbulence intensity* ditetapkan pada 10 m/s dan 10% masing-masing. Untuk ketiga-tiga kes ini, suhu adalar ditetapkan pada 293 K pada saluran masuk udara sejuk dan 1000 K pada salur masuk udara panas. Dalam kajian ini juga, dinding bagi salur penyejuk dianggap *adiabatic* dan tiada kegelinciran yang berlaku. Manakala, kedua-dua tekanan pada salur masuk dan salur keluar adalah sama. Setelah disimulasi menggunakan CFD, graf prestasi salur pendingin akan diperolehi. Keputusan menunjukkan, keberkesanan salur pendingin akan meningkat dengan meningkatnya kelajuan, kurangnya *turbulence intensity*, dan ukuran besar bagi saluran masuk pendingin.

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LIST OF ABBREVIATIONS

°C = Degree Celcius
2D = Two Dimensional
3D = Three Dimensional
BL = Boundary
CFD = Computational Fluid Dynamics
DNS = Direct Numerical Simulation
FEA = Finite Element Analysis
GAMBIT = Geometry and Meshing Building Intelligent Toolkit
HP = Horse Power
HVAC = Heating Ventilation Air Conditioning
K = Kelvin
k-ε = *k-epsilon*
LES = Large-Eddy Simulation
m/s = Metre per second
Mm = Milimetre
PDE = Partial Differential Equation
RANS = Reynolds Averaged Navier-Stokes
RSM = Reynolds Stress Models

CHAPTER 1

INTRODUCTION

1.1 Introduction

Gas turbines play a vital role in the today's industrialized society, and as the demands for power increase, the power output and thermal efficiency of gas turbines must also increase. One method of increasing both the power output and thermal efficiency of the engine is to increase the temperature of the gas entering the turbine.

In the advanced gas turbines of today, the turbine inlet temperature can be as high as 1500°C. However, this temperature exceeds the melting temperature of the metal airfoils. Therefore, it is imperative that the blades and vanes are cooled, so they can withstand these extreme temperatures. Cooling air around 650°C is extracted from the compressor and passes through the airfoils. With the hot gases and cooling air, the temperature of the blades can be lowered to approximately 1000°C, which is permissible for reliable operation of the engine. It is widely accepted that the life of a turbine blade can be reduced by half if the temperature prediction of the metal blade is off by only 30°C.

In order to avoid premature failure, designers must accurately predict the local heat transfer coefficient of metal temperatures. By preventing local hot spots, the life of the turbine blades and vanes will increase. However, due to the complex flow around the airfoils it is difficult for designers to accurately predict the metal temperature.

Figure 1.1 (a) shows the heat flux distribution around an inlet guide vane and a rotor blade. At the leading edge of the vane, the heat transfer coefficients are very high, and as the flow splits and travels along the vane, the heat flux decreases. Along the suction side of the vane, the flow transitions from laminar to turbulent, and the heat transfer coefficients increase.

As the flow accelerates along the pressure surface, the heat transfer coefficients also increase. The trends are similar for the turbine blade; the heat flux at the leading edge is very high and continues decrease as the flow travels along the blade, on the suction surface and the heat flux sharply increases the heat transfer on the pressure surface increases as the flow accelerates around the blade.

Gas turbine technology has steadily advanced since its inception and continues to evolve; research is active in producing ever smaller gas turbines. Computer design, specifically CFD and Finite Element Analysis (FEA) along with material advances, has allowed higher compression ratios and temperatures, more efficient combustion and better cooling of engine parts.

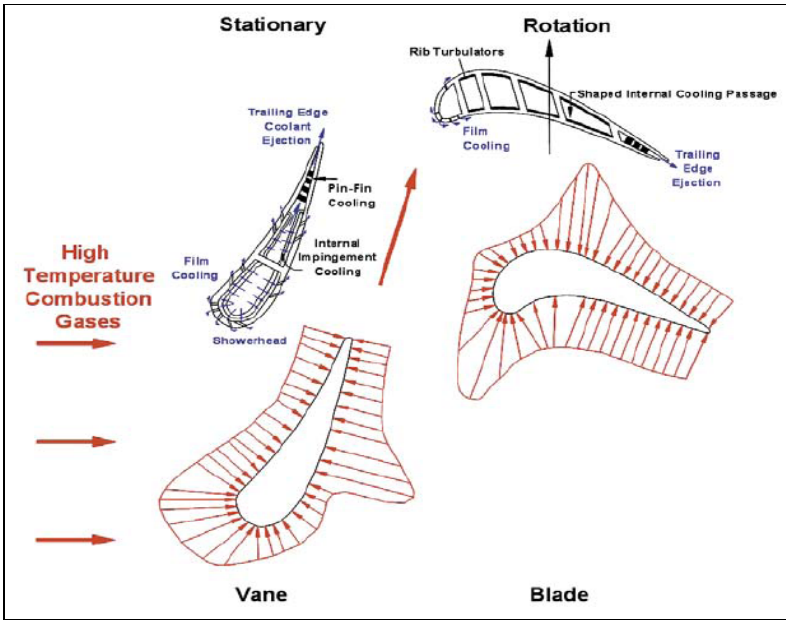

Figure 1.1 (a): Cross-Sectional View of a Cooled Vane and Blade

(Source: http://www.netl.doe)

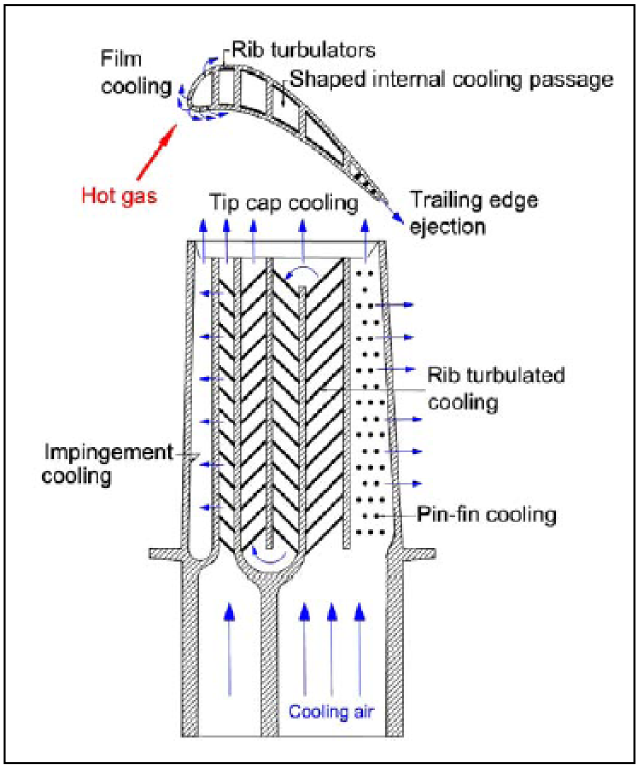

Figure 1.1 (b): Schematic of a Modern Gas Turbine Blade with Common Cooling (Source: http://www.netl.doe)

1.2 History of Gas Turbine

The history of gas turbine start 150 years ago, when Hero's Engine (*aeolipile*), apparently Hero's steam engine was taken to be no more than a toy, and thus its full potential not realized for centuries. In 1791, a patent was given to John Barber, an Englishman, for the first true gas turbine. His invention had most of the elements present in the modern day gas turbines. The turbine was designed to power a horseless carriage. Then it expanded in 1903 when Egidius Elling, was able to build the first gas turbine that was able to produce more power than needed to run its own components, which was considered an achievement in a time when knowledge about aerodynamics was limited. Using rotary compressors and turbines it produced 11 HP (massive for those days). His work was later used by Sir Frank Whittle. 1930: Sir Frank Whittle patented the design for a gas turbine for jet propulsion. His work on gas propulsion relied on the work from all those who had previously worked in the same field and he has himself stated that his invention would be hard to achieve without the works of Egidius Elling. The first successful use of his engine was in April 1937.

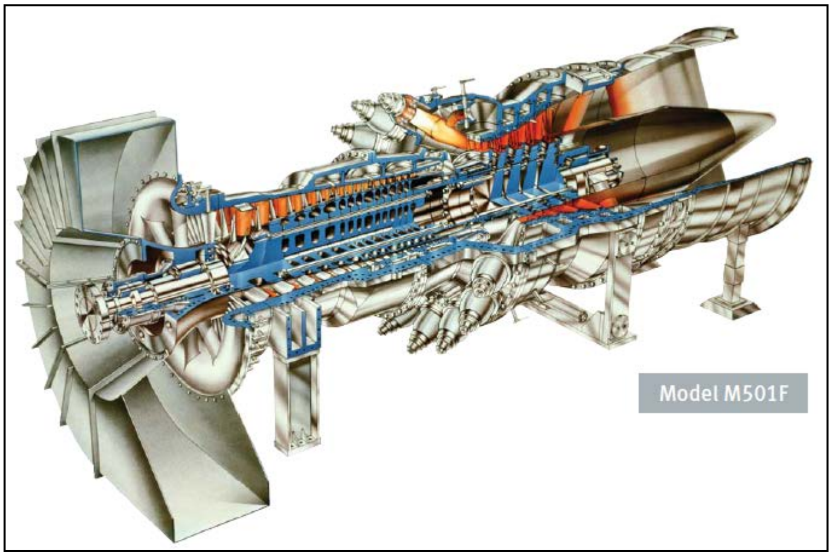

Figure 1.2: Current gas turbine

(Source: http://www.doosanheavy.com)

1.3 Gas Turbine Development

Gas turbine first successful development is in the 1930s. The early gas turbine built in the 1940 and even in 1950s had simple cycle efficiencies about 17 percent because of the low compressor and turbine efficiencies and low turbine inlet temperature due to metallurgical limitation at that time. Therefore, gas turbines found only limited use despite their versatility and their ability to burn a variety of fuels. So, the efforts to improve the cycle efficiency concentrated in three areas:

a. Increasing the turbine inlet (or firing) temperatures: This has been the primary approach taken to improve gas turbine efficiency. The turbine inlet temperatures have increased steadily from 540 ˚C in the 1940s to 1425 ˚C and even higher today. These increases were made possible by the development of new materials and the innovative cooling technique for the critical components such as coating the turbine blades with ceramic layer and cooling the blade with the discharge air from the compressor. Maintaining high turbine inlet temperatures with an air-cooling technique requires the combustion temperature to be higher to compensate for the cooling effect of the cooling air.

b. Increasing the efficiencies of turbomachinery components: The performance of early turbines suffered greatly from the inefficiencies of turbines and compressors. However, the advent of computers and advanced techniques for computer-aided design made it possible to design these components aerodynamically with minimal losses. The increased efficiencies of the turbines and compressors resulted in a significant increase in the cycle efficiency.

c. Adding modifications to the basic cycle: The simple-cycle efficiencies of early gas turbine were practically doubled by incorporating intercooling, regeneration (or recuperation), and reheating. These improvements, of course, come of expand of increased the initial and operation costs, and they cannot be justified unless the decrease in fuel costs offsets the increase in the other cost. The relatively low fuel prices, the general desire in the industry to minimize installation costs, and the tremendous increase in the simple-cycle efficiency to about 40 percent left desire for opting for these modifications. [1]

1.4 Gas Turbine Theory of Operation

The Brayton cycle was first proposed by George Brayton for use in the reciprocating oil burning engine that he developed around 1870. Today, it is used for gas turbines only where both the compression and expansion processes take place in rotating machinery. Gas turbines usually operate on an open cycle, as shown in figure 1.4 (a). The fresh air at ambient condition is drawn into the compressor, where its temperature and pressure raised.

The high pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure. The resulting high-temperature gases than enter the turbine, where they expand to the atmospheric pressure while producing power. The exhaust gases leaving the turbine are thrown out (not recirculated), causing the cycle to be classified as an open cycle.

The open gas turbine cycle described above can be modeled as a closed cycle, as shown in figure 1.4 (b), by utilizing the air-standard assumptions. Here the compression and expansion processes remain the same, but the combustion process is replaced by a constant-pressure heat-addition process from an external source, and the exhaust process is replaced by a constant pressure heat-rejection process to the ambient air. The ideal cycle that the working fluid undergoes in this closed loops in the Brayton cycle, which is made up of four internally reversible processes:

a. Isentropic compression (in a compressor)
b. Constant- pressure heat addition
c. Isentropic expansion (in a turbine)
d. Constant- pressure heat rejection

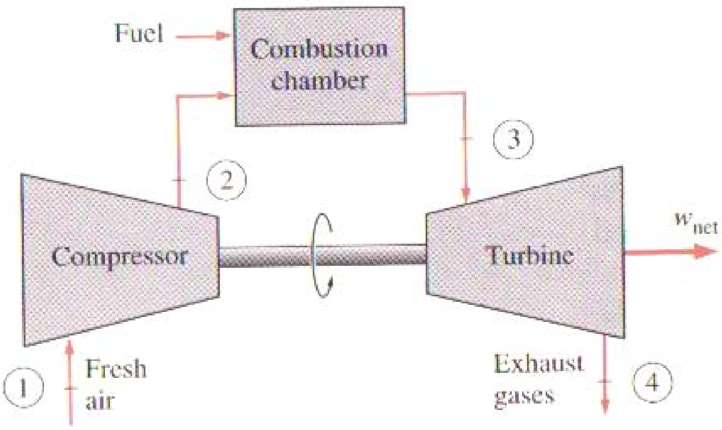

Figure 1.4 (a): An open cycle gas turbine engine

(Source: Thermodynamics 6th edition)

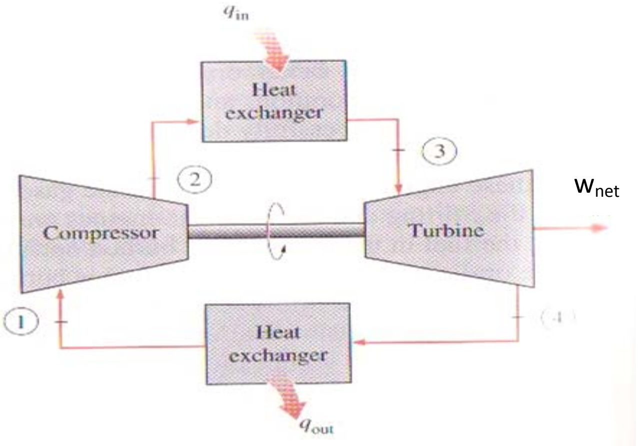

Figure 1.4 (b): A closed cycle gas turbine engine

(Source: Thermodynamics 6th edition)

1.5 Type of Gas Turbine

There are three main section of a simple gas turbine, which consists of a compressor, a combustor, and a power turbine. In a simple gas turbine cycle, low pressure air is drawn into a compressor (state 1) where it is compressed to a higher pressure (state 2). Fuel is added to the compressed air and the mixture is burnt in a combustion chamber. The resulting hot products enter the turbine (state 3) and expand to state 4. Most of the work produced in the turbine is used to run the compressor and the rest is used to run auxiliary equipment and produce power.

1.5.1 Gas Turbine with Regeneration

One variation of this basic cycle is the addition of a regenerator. A gas-turbine with a regenerator (heat exchanger) recaptures some of the energy in the exhaust gas, pre-heating the air entering the combustor. This cycle is typically used on low pressure ratio turbines.

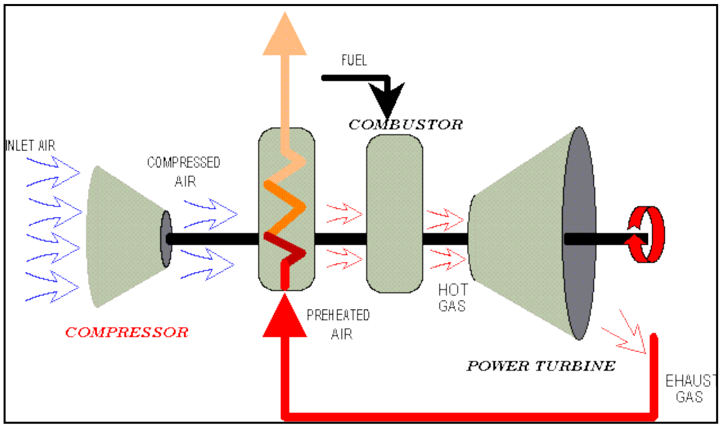

Figure 1.5 (a): Turbines using this cycle are, *Solar Centaur* / 3500 horsepower class up to the *General Electric Frame 5*

(Source: http://www.massengineers.com)

1.5.2 Gas Turbine with Intercooling

The second is gas-turbines with high pressure ratios can use an intercooler to cool the air between stages of compression, allowing you to burn more fuel and generate more power. In this case, the limiting factor on fuel input is the temperature of the hot gas created, because of the metallurgy of the first stage nozzle and turbine blades. With the advances in materials technology this physical limit is always rise up.

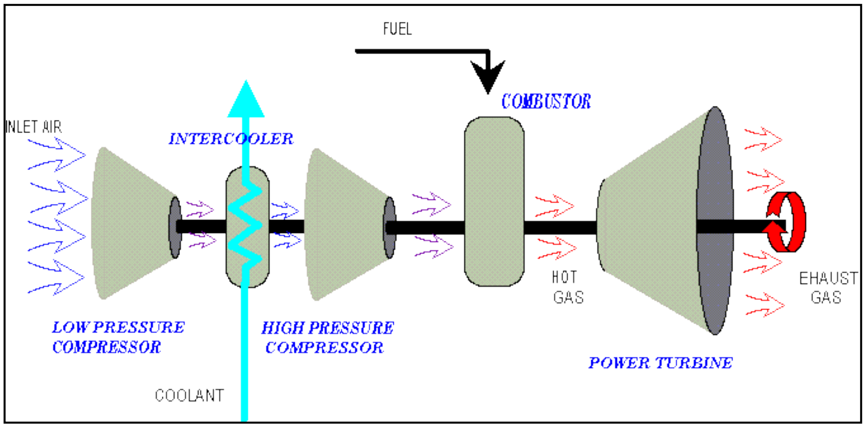

Figure 1.5 (b): One turbine using this cycle is *General Electric LM1600 / Marine version*

(Source: http://www.massengineers.com)

1.6 Blade Cooling

Over the past fifty years, aircraft and power generation gas turbine designers have endeavored to increase the combustor exit and high-pressure turbine stage inlet temperatures. With higher combustor exit temperatures, improved efficiency and reduced fuel consumption can be achieved. Similarly, in aircraft application, the higher temperatures lead to increased thrust. Unfortunately, these higher temperatures have jeopardized the integrity of the high-pressure turbine components and specifically the turbine blades.