IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 30-35
www.iosrjournals.org

Optimization Of Pattern Factor Of The Annular Gas Turbine Combustor For Better Turbine Life

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Abstract: *Combustion chamber being an integral part of a Gas Turbine Engine has been studied in depth. The successful Combustion chamber design involves a complex coupling of aerodynamics, thermodynamics and chemical kinetics of reaction. There are various parameters which decide the successful design of combustion chamber, one of them is the exit profile factor or pattern factor. The exit temp profile directly decides the life of the turbine blade and hence the overall engine life, thus it's an important parameter to be studied. In the present study we will consider three different designs with modification being implemented, based on the result of the previous case and towards better exit temperature profile. Thus in each step we will try to optimize the temperature profile at the exit. CFD tool will be extensively being use for studying this purpose.*

Keywords- *Combustor, Pattern Factor, GAMBIT, FLUENT (CFD).*

I. INTRODUCTION:

An overview of current practice for design and development of aero gas turbine combustors is presented here. A gas turbine combustor is a device for raising the temperature of the incoming air stream from compressor by the addition and combustion of fuel. The purpose of the combustion system is to convert chemical energy of fuel air mixture to thermal energy of combustion products that comes out of the combustor to drive the turbine.

A.Pattern Factor: It is also called Temperature Traverse Quality.-One of the most important and at the same time , most difficult problems in design and development of gas turbine combustion chambers that of achieving a satisfactory and consistent distribution of temperature at exit gases discharging into turbine. Pattern factor highlights the overall temperature distribution factor.

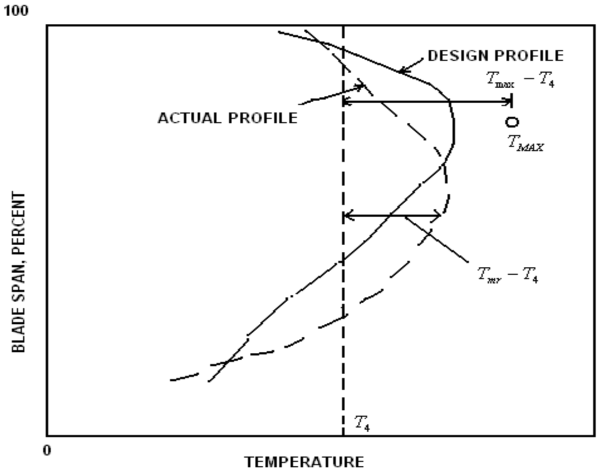
$$\text{Pattern Factor} = \frac{T_{\text{Max exit}} - T_{\text{Avg.exit}}}{T_{\text{Avg.exit}} - T_{INLET}}$$

It's Significance: It affect the power output of the engine and the life and durability of the turbine blade downstream of combustor.

B.Radial Pattern Factor or Profile Factor: It indicates the radial temperature distribution profile. It is obtained by adding together the temperature measurement around each radius of the liner and then dividing by the number of locations at each radius, i.e. by calculating arithmetic mean at each radius.

$$\text{RPF} = \frac{T_{0\,\text{Avg.@ radial distanceR}} - T_{0\_\text{Avg.exit}}}{T_{0\_\text{Avg.exit}} - T_{0\_INLET}}$$

It's Significance: It directly indicates the quality of temperature profile at the combustor exit. The desired average radial distribution of temperature profile is that which peaks above the mid-height of the blade. The objective is to provide lower temperature at the turbine blade root, where mechanical stresses are highest, and at the tip of blade which is most difficult to cool.



Showing the temperature profile at exit of combustor

II. GEOMETRIC DETAILS OF COMBUSTOR:

The combustor geometry was created using CAD tool. The full Annular combustor contains 12 injectors. But due to constrain in Computational capability only 30 degree sector (consisting only one injector) of the whole geometry was designed and analyzed subsequently. Here we are considering three stages of design of 30 degree sector of annular combustor i.e., stage-1 design, stage-2 design, stage-3 design.

The Geometry features of the combustor under study are highlighted below: The full combustor length from the last compressor stage to the start of nozzle guide vanes was around 0.35 m. Each component from fuel injector to the annulus was created separately and then assembled to form the 30 degree sector of the flow field geometry.

Annular combustor

In stage-1 design, the simple combustor with one row of primary holes, secondary holes, dilution holes, respectively are only considered as liner cooling holes. Dome cooling holes are avoided in stage-1 design to study the effect of temperature on dome section.

In stage-2 design, two rows of dome cooling holes of totally 30 holes (each row 15 holes) are considered along with primary, secondary, dilution holes.

In stage-3 design, the liner cooling holes are same as stage-2 design but there is slight change in design geometry i.e., lower liner at exit is elevated upward and the upper liner at exit is straightened.

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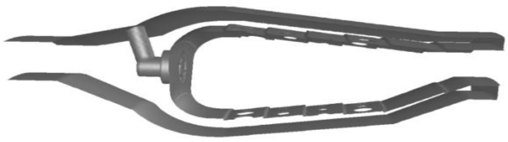
The 30 degree sector of designed stage-2 combustor



The 30 degree sector of designed stage-3 combustor

Since we are considering three stages of combustor design (stage-1, stage2, stage3), the dome cooling holes in the dome section of the liner of stage-1design has been neglected to study its effect of temperature contour of combustor but it has been considered in stage-2 design and stage-3 design of the annular combustor design.

In stage-1, to compensate the area distribution of dome cooling additional area has been provided for primary and dilution holes.

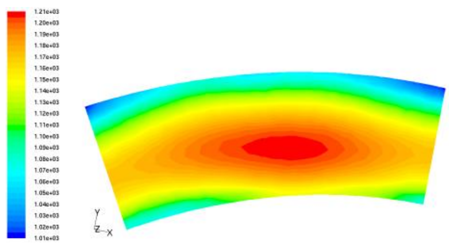
In stage-2, dome cooling holes has been considered as per above area distribution. There are two rows of holes are allocated for dome cooling of totally 30 holes, each inclined at 20 degree to the combustor axis(each row has 15 holes). Same area distribution has been considered for stage-3 with some geometric change in design.

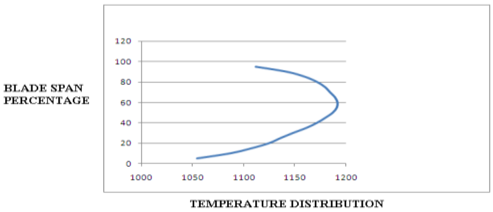
Solution Procedure:
This section is intended to highlight the various steps taken right from the import of the Mesh file to the final Solution Convergence. Steps as shown in the above flow chart are:

- Grid Check And Improvement
- Defining Models
- Adding Boundary Conditions
- Solution Control And Initialization
- Setting Convergence Criteria.
- Towards Grid Independent Solution

III. RESULTS AND DISCUSSION:

For stage-1:



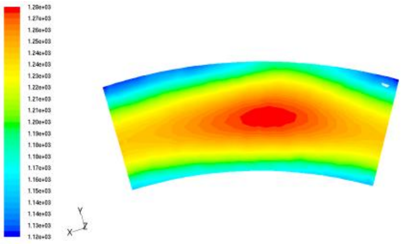


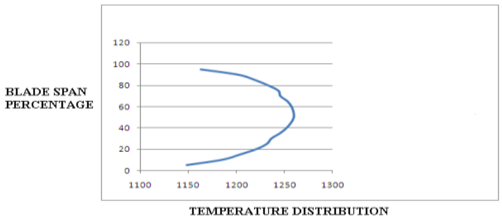
Temperature contour at exit plane Radial pattern factor of the combustor

In stage-1 design, due to the absence of dome cooling hole in the dome section the high temperature after combustion directly affects the dome section and results in hot spot formation on dome wall. Due to high temperature formation and excessive thermal stress there occurs thermal buckling.

The temperature contour at exit plane of stage-1 design is shown. This exit plane temperature profile obtained for stage-1 design is not so good because the temperature at root section of the turbine inlet is high. This may result in high thermal stress acting on root section of the turbine blade.The radial pattern factor obtained for stage-1 design is poor one because of high temperature formation at turbine inlet root section.

For stage-2:



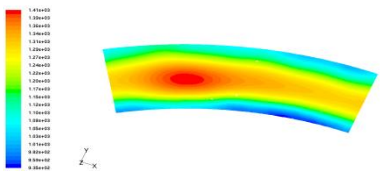


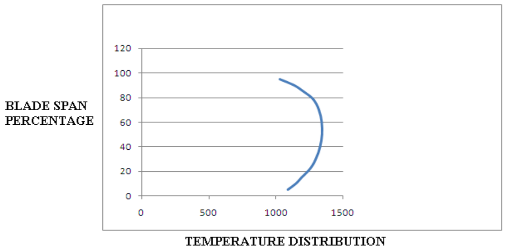
Temperature contour at exit plane of combustor Radial pattern factor of the combustor

The hot spot formation at the dome section is reduced due to introducing dome cooling holes.

The temperature contour at the exit plane of the combustor of stage-2 design is better than stage-1 design because the temperature values obtained at root and tip of turbine blade inlet of stage-2 design is lesser than temperature values obtained at tip and root stage-1 design. Radial pattern factor obtained at the exit of the combustor of stage-2 design is not so good and it seems to be better when compared RPF of stage-1 design.

For stage-3:





Temperature contour at exit plane Radial pattern factor of the combustor

The radial pattern factor obtained by stage-3 design is much better than other two designs stages. The temperature profile at exit plane of the stage-3 design combustor is shown**.**This temperature profile at the exit plane of stage-3 design results in less thermal stress acting on root and tip section of turbine blade.

The typical values of RPF are 0.12 and 0.30 respectively.[1]
RPF for stage-1=0.06
RPF for stage-2=0.05
RPF for stage-3=0.14

IV. CONCLUSION:

The Three Dimensional flow structure of the aircraft engine combustor is established, considering PDF model with 20 species to judge the accuracy of the results. In stage-2 design two rows of Dome cooling holes are been implemented such that it provided the blanket of air coating inside the dome section thus avoids temperature hotspot formation.Better recirculation is obtained in stage-3 design than stage-1 and stage-2 design.
Pattern factor i.e., temperature profile at exit plane of the combustor has been compared between three design stages and optimized. The temperature profile obtained at the exit plane of stage-3 design is concluded as better temperature profile when compared to other previous designs.

V. FUTURE WORKS:

Though this work was done only on a limited section of this wide field of Aerospace domain, yet we must not forget the bigger picture that evolves subsequently. With the growing concern of fuel crisis, the concern of growing pollution and health hazards caused by burning hydrocarbon fuels, the concern of Global Climate change due to increasing CO_2 level in atmosphere. With all these problems hovering overhead, clearly the Future belongs to that part of the century where we must take steps not only to reduce the emissions and optimize the performance, but eliminate them once and for all.To obtain better performance of the combustor, further increase in dome cooling holes, liner cooling holes, injector design, bleed holes are to be considered.

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