Research of Flame Stabilization and Mixing Mechanisms for Turbine Inter-vane Burner Based on Jet-vortex Flow

Haifei Zheng\(^1\), Hao Tang\(^*\), Xingya Xu\(^1\), Ming Li\(^2\), Yinli Liu\(^1\)

\(^1\) College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing Jiangsu, 210016, China
\(^2\) AVIC Engine Establishment, Beijing 100009, China

Abstract

In order to meet the requirement of flame stabilization and intensify the mixing, a new injection configuration, named double-effect injection configuration, is designed and that is the two secondary injections have been allocated with different functions to achieve the purpose of flame stabilization and intensifying mixing. The effects of the variation of secondary injections on flame stabilization, mixing and combustion performance were studied by using numerical simulation method. The conclusions are that by double-effect injection configuration, a stable recirculation zone can be formed in the cavity to stabilize the combustion flame, and the mixing effect can be intensified; and the temperature distributions at this combustor exit are more symmetric; and the influence of angle variation of secondary jet flow based on double-effect injection configuration is weaker, but it can be seen that model-1 (50° and 45° for two injection angle) has highest combustion efficiency and lowest total pressure losses.

Keywords: Turbine Inter-guide-vane Burning, Jet-vortex scheme, Flame Stabilization, Mixing

1. Introduction

At present, there are for two main research schemes for Turbine Inter-guide-vane Burning (TIB) technology. First one \(^1\), \(^2\) is jet-whirl scheme. Second \(^3\) is jet-vortex scheme. It is well known that the centrifugal acceleration of centrifugal combustion in jet-whirl scheme \(^1\), \(^2\) is inversely proportional to the radius of the cavity. If one needs to scale the TIB technology for a larger spool of turbine components, the prospective performance index cannot be met by using the jet-whirl scheme. Trapped vortex cavity \(^4\) is used in the present study of jet-vortex scheme proposed by Sekar \(^3\). Compared with the trapped vortex combustor, turbine guide vanes and radial vane cavities are augmented inside the main flow channel of the turbine inter-guide-vane burner. These augmentations influence the formation of the recirculation zone in the cavity, and the mixing effect of main flow and intermediate combustion products.

\* Corresponding author. Tel.: 86-025-84892217  E-mail address: hao.tang@nuaa.edu.cn

This work is supported by the National Natural Science Foundation of China (51076064) and Funding of Jiangsu Innovation Program for Graduate Education (CXLX12_0152)
In order to meet the requirement of flame stabilization and intensify the mixing effect, a new injection configuration, named double-effect injection configuration, is designed and that is the two secondary jet flows have been allocated with different functions to reach the purpose of flame stabilization and intensifying mixing, and the jet angles are redesigned compared with literatures [3-6]. The effect of the variation of secondary jet flow on flame stabilization, mixing and combustion performance is studied by using numerical simulation method.

2. Jet-vortex scheme and double-effect injection configuration for secondary flow

Trapped vortex cavity is employed at the bottom of the turbine guide vanes in jet-vortex scheme as showed in Fig.1. The functions of two secondary jet flows are innovatively allocated in a way that secondary jet flow a is injected from the upper middle of the front wall of the cavity, directed towards the main flow channel to intensify the mixing effect. And secondary jet flow b is injected from the middle of the back wall, directed towards the bottom of the cavity to enhance the recirculation zone to stabilize the combustion flame. This configuration is called as double-effect injection configuration as showed in Fig.2.

In this research, there are 4 models to explore the effect of the secondary jet flow angle on the flame stabilization and mixing. Angles for Model-1’s secondary jet flow a and b are 50° and 45°; The angles for Model-2 are 50° and 60°; The angles for Model-3 are 60° and 60°. Model-0 shows the air injection method of the secondary jet flows in literatures, and the angles for Model-0 are all 0°.

3. Numerical Methods

The main flow inlet and secondary flow inlet of TIB combustor are all mass-flow inlets and the outlet is of type pressure outlet boundary condition, and periodic boundary condition is applied to the lateral sides of the flow domain. The rest of the surfaces are all set to wall boundary conditions. Fuel is injected from various locations independently in parallel jets from the back wall of the cavity. Hexahedral mesh is employed in the meshing of computational fluid domain. Pressure-based implicit steady solver, least square cell based method, standard scheme, SIMPLEC algorithm and second order upwind scheme are used to simulate the processes of flow and combustion inside TIB combustor. Scale-Adaptive Simulation viscous model and EDC combustion model are adopted to simulate the turbulent flow and combustion.

4. Results and Conclusion

A. Analysis of the flame stabilization mechanism

The distribution of the flow field inside the cavity of 4 models is illustrated in Fig.3. The chaotic distribution of the flow field in the model-0 cavity in Fig.3 is bad for flame stabilization. Model-1,2 and 3 all have a stable recirculation zone inside the cavity, as showed in Fig.3. These are the results obtained by new functions and allocations for the secondary jet flows of Jet-vortex scheme. The analysis for the flame stabilization mechanism of the recirculation zone in the cavity of model-1 is found in Fig.4. As showed in
Fig.4, a recirculation zone section is taken across the vortex core (point O) and named as O section. The ignition source may not be in the O section, lying in front of or behind it, depending largely on the fuel-air ratio. But the ignition source must be in the recirculation zone to stabilize the combustion flame.

**B. Analysis of mixing intensity**

The distribution of hydroxyl (OH) mass fraction is adopted and OH is typically found within and following the primary reaction region of a flame, which is used as a marker for the location of intermediate combustion products. OH can be utilized to provide the location of high-temperature combustion products impinging into the main channel [7]. High OH mass fraction in a region proves to be complete burning, which in turn indicates a good mixing. Fig.5 presents the distribution of OH mass fraction along the X direction (the chord direction of turbine guide vane) for 4 models. The distributions of OH mass fraction for model-1, 2 and 3 show very similar values. But the distribution of model-0 is under the other curves. This illustrates that OH content of the latter three models is larger than model-0.

Fig.6 presents the distribution of OH mass fraction along the Y direction (the height direction of the turbine guide vane) for 4 models. This also has found that the mixing intensity is higher for model-1, 2 and 3. And these three models are all based on double-effect injection configuration. Since the distributions of OH mass fraction of model-1, 2 and 3 tend to overlap, and this shows that the influence of the angle variation on the mixing intensity is inconspicuous.

**C. The analysis of temperature field and combustion performance**

Fig.7 presents the temperature distribution along the Y direction at the exit of the guide vane for 4 models. The temperature distributions of the three models, such as model-1, 2 and 3, are extremely similar and overlaps basically, which presents the trend of high temperature on the top and bottom of the guide vane and low temperature on the middle of the guide vane. The temperature distribution of model-0 is significantly different from other three models. There is a sudden temperature jump at the middle of the guide vane along the height direction. But the temperature distribution for the other three models is more
symmetric than model-0. So this indicates that the mixing effect of model-1, 2 and 3 is preferable to the mixing effect of model-0. Fig.8 presents combustion efficiency for 4 models. The combustion efficiency for model-0 is below 99%. Model-1 gets the highest combustion efficiency which is 99.171%. The total pressure losses for 4 models are shown in the Fig.9. Model-1 has the lowest total pressure losses(6.748%).

D. Conclusion

Compared with the air intake method from literatures, the conclusion is that by double-effect injection configuration for secondary jet flows, a stable recirculation zone can be formed in the cavity in which a stable ignition source exists to stabilize the combustion flame and the mixing of main flow and intermediate combustion products can be intensified. The temperature distributions at the exit of the guide vane for model-1, 2 and 3 are more symmetric than model-0, and this indicates that the mixing effect of latter 3 models is better than model-0. The influence of angle variation of this two secondary jet flows is weaker, but model-1 has the highest combustion efficiency and lowest total pressure losses.

References