ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Computational Prediction of Role of Vortex Generators in Combustion Enhancement

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Abstract:

The main objective is to enhance the combustion process in the gas turbine engines using delta-wing type vortex generators. This type of vortex generators are used to achieve rapid mixing through eddying motion of vortices which produce no recirculation zones and low pressure drop along the mixing plane. A detailed analysis of velocity vector, static pressure, and the intensity of turbulence generated by the single pair and double pair of vortex generators are presented as l/b ratio is varied. The results obtained through CFD analysis indicate that the optimum vortex generator configuration which produces maximum turbulence intensities with a less amount of recirculation zones at a relatively low pressure drop.

Keywords:

vortex generators, combustion, turbulence, pressure, CFD

INTRODUCTION:

The combustion chamber has the difficult task of burning large quantities of fuel, supplied through the fuel spray nozzles, with extensive volumes of air, supplied by the compressor, and releasing the heat in such a manner the air is expanded and accelerated to give a smooth stream of uniformly heated gas at all conditions required by the turbine. This task must be accomplished with the minimum loss in pressure and with the maximum heat release for the limited space available. The combustion chamber has certain design and operational requirements. The gas turbine engine operates on a constant pressure cycle, therefore, during the process of combustion pressure loss should be minimum. However, achieving sufficiently good mixing within limited space and residence time available in the mixing section of a gas turbine combustor is not a simple task.

Difficulties arise due to the requirements of the combustor design, such as mixing, flashback safety and pressure drop.in order to obtain proper mixing of the fuel and the airstreams both large scale distributions and fine-scale mixing are necessary. However, given the fact the mass flow rate of fuel is very less as compared to the mass flow rate of air stream and the supply pressure of the fuel injection is limited. A simple way of overcoming several problems associated with achieving proper mixing quality is utilizing the momentum of airstream via delta-wing type vortex generators. By using this type of vortex generators, longitudinal vortices created by the vortex generators which are employed for distribution of fuel over the airstream and subsequent fine scale mixing. The requirements that no recirculation zones can be tolerated and the pressure drop due to vortex generators has to be low as possible with maximum amount of turbulence which generate exclusively stream wise vortices.

DESIGN:

Delta wing type vortex generators are designed based on the design implemented on the combustor of the GT24/GT26 series industrial gas turbines. A single pair and double pair of vortex generators are employed in the combustor are designed as l/b ratio is varied with h/b ratio is fixed. A more detailed view of vortex generator is presented in Fig. 1.

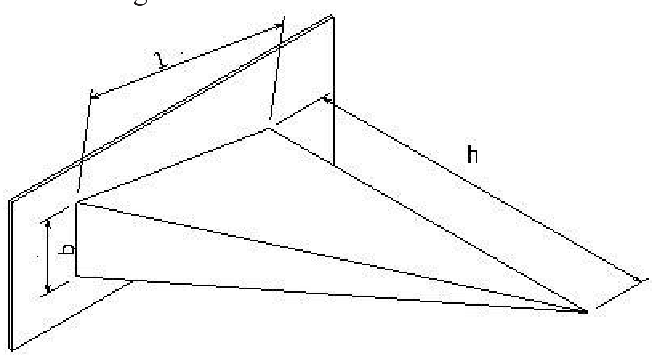

Fig. 1 Detailed view of vortex generator

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COMPUTATIONAL TECHNIQUES AND PROCEDURE

The mixing characteristics reported here have been carried out in CFD software with the help of k-epsilon turbulence model using fluent solver. The k-epsilon model focuses on the mechanisms that affect the turbulent kinetic energy. The k-epsilon model is the most widely used and validated turbulence model.

It has achieved notable successes in calculating a wide variety of thin shear layer and recirculating flows without the need for case-by case adjustments of the model constants. These advantages make the k-epsilon model reliable for investigating the mixing characteristics in the combustor in which vortex generators are employed. Here, fluent solver is used to solve the computational problem. The inlet conditions are velocity was 40 m/s and the other parameters are sea-level conditions.

SINGLE PAIR OF VORTEX GENERATORS:

The mass and momentum of the flow are not high enough to achieve the proper mixing quality within a limited amount of space, methods of utilizing the momentum of the main stream via vortex generators have been investigated. The main requirements are as follows

1.Low pressure drop

2.No recirculation zones or regions of low velocity along the mixing section

3.Simple design

4.Maximum turbulence level

The requirements of low pressure drop and high safety against flame in the mixing zone led exclusively to delta-wing type vortex generators which can generate stream wise vortices without any recirculation zones. In this type, pair of vortex generators is fixed on the left and right wall of the non-circular channel is shown in Fig.2.

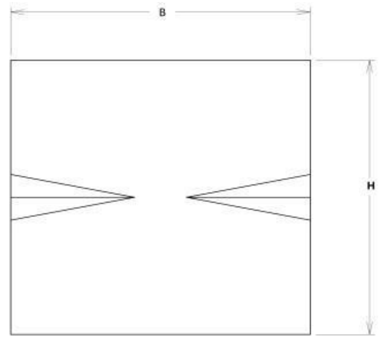

Fig. 2 Channel with single pair of vortex generators as viewed from inlet

The analysis is carried in order to optimize the intensity of turbulence, the flow streamlines downstream and the pressure drop. The measurement planes are perpendicular to the flow direction and located at z/h = 0.1,0.5,1,2,3. The height to width ratio of the vortex generator is fixed as the length to width ratio of the vortex generator is varied in four discrete steps. These four steps are labeled as versions A: length 50 percent lesser than with, B: length equal to width, C: length equal to twice the width, D: length equal to thrice the width.The velocity vectors are taken downstream of the vortex generators at z/h=0.1 plane perpendicular to the flow direction

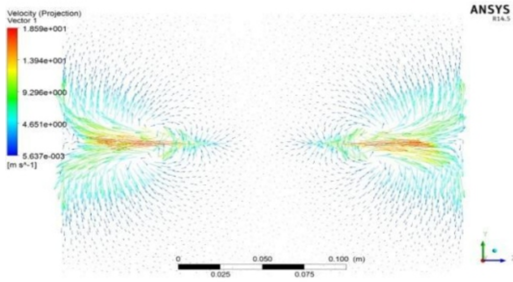

Fig. 3 Tangential velocity vectors at z/h=0.1 plane of vortex generator version A

In Fig. 2-5, a series of contour plots showing the tangential streamline pattern of the flow and tangential velocity components variation along the plane. This plots are useful to visualize the recirculation zones or low velocity zones. In the geometries, namely version C and D give rise to recirculation zones at this plane immediately downstream of the vortex generator. The other geometries, namely A and B do not exhibit much recirculation zones.

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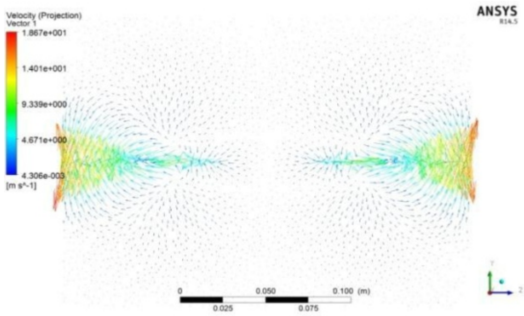

Fig. 4 Tangential velocity vector at z/h=0.1 plane of vortex generator version B

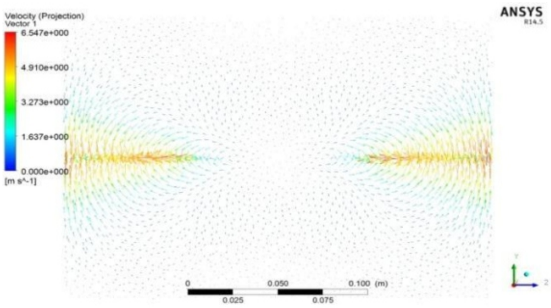

Fig. 5 Tangential velocity vector at z/h=0.1 plane of vortex generator of version C

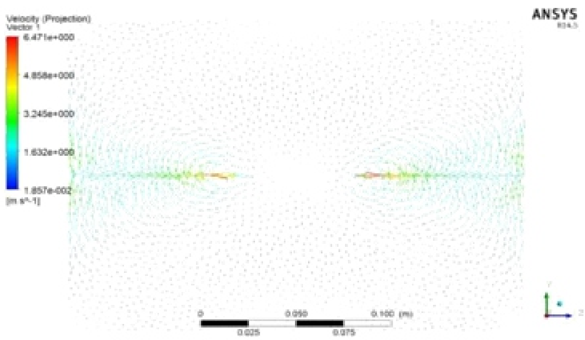

Fig. 6 Tangential velocity vector at z/h=0.1 plane of vortex generator version D

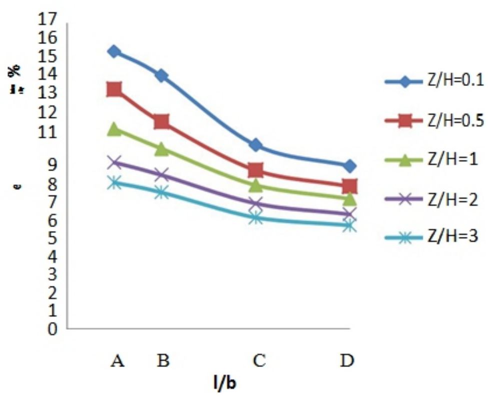

Fig. 7 Turbulence intensity at five successive planes downstream of vortex generator as f(length/width) of the vortex generator

The intensity of turbulence created by the version A is greater than the other geometries, namely version B, C and D and it is clear from the Fig. 6 that the intensity of turbulence is decreasing as moving downstream of the vortex generator.

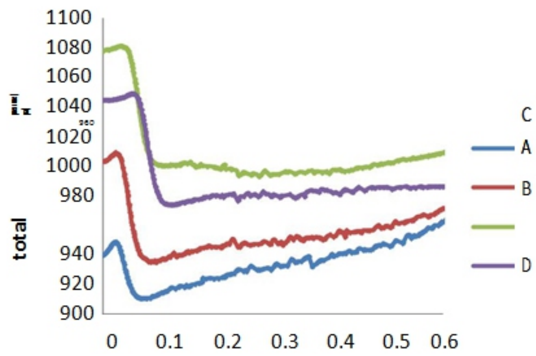

Fig. 8 Total pressure at the centerline of the channel as a function of channel length

The total pressure values are taken at the centerline of the channel are shown in Fig. 7. The pressure drop is calculated by taking the difference between the total pressure at location z/h=0.1 upstream of the vortex generator and the total pressure at location z/h=3 downstream of the vortex generator. From the plot, the pressure drop of version A vortex generator is much less than the other geometries, namely version B, C and D.

DOUBLE PAIR OF VORTEX GENERATORS

In this arrangement, two pair of identical vortex generators is mounted on the four walls of the channel is shown in Fig. 9. The same boundary conditions are specified; inlet as velocity 40 m/s and the other parameters are sea-level conditions.

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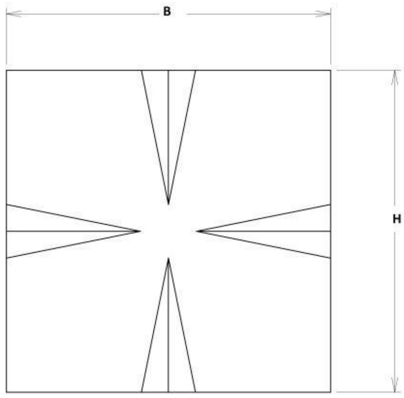

Fig. 9 Channel with double pair of vortex generators as viewed from inlet

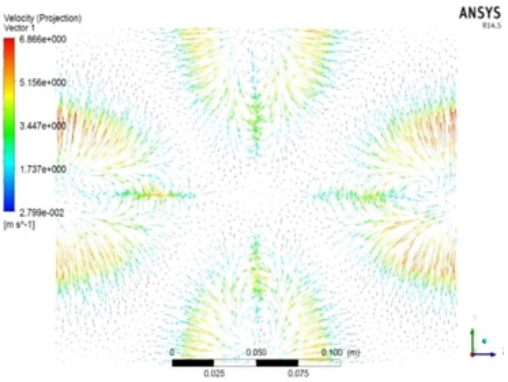

Fig. 10 Tangential velocity vectors at z/h=0.1 plane of vortex generator version A

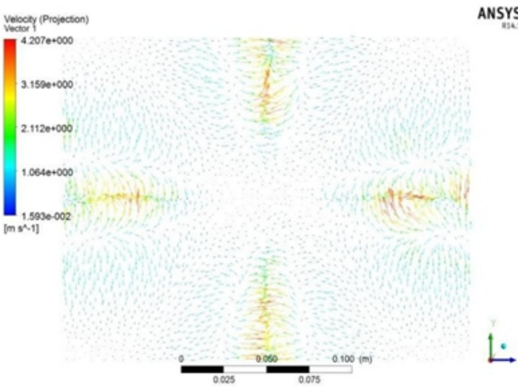

Fig. 11 Tangential velocity vectors at z/h=0.1 plane of vortex generator version B

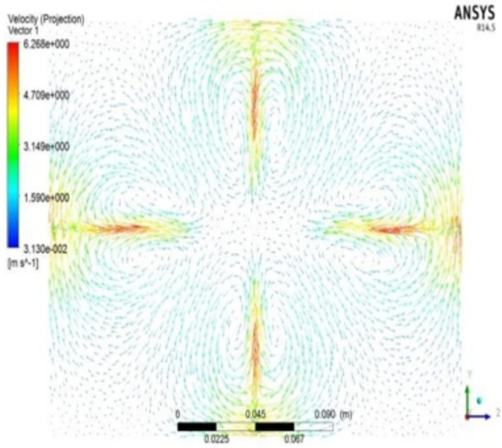

Fig. 12 Tangential velocity vectors at z/h=0.1 plane of vortex generator version C

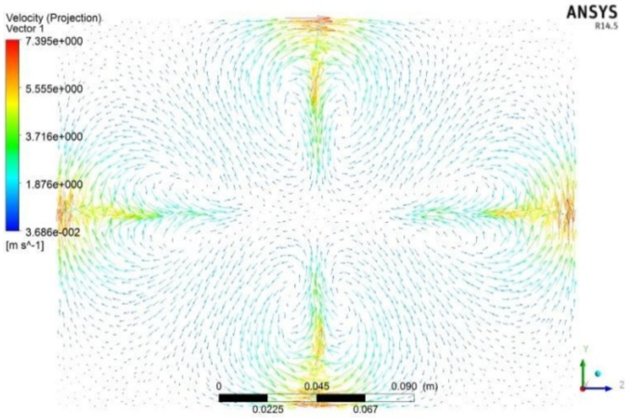

Fig. 13 Tangential velocity vectors at z/h=0.1 plane of vortex generator version D

In Fig. 8-11, a series of contour plots showing the tangential streamline pattern of the flow and tangential velocity components variation along the plane. This plots are useful to visualize the recirculation zones or low velocity zones. In the geometries, namely version A and B give rise to recirculation zones at this plane immediately downstream of the vortex generator. The other geometries, namely C and D do not exhibit much recirculation zones.

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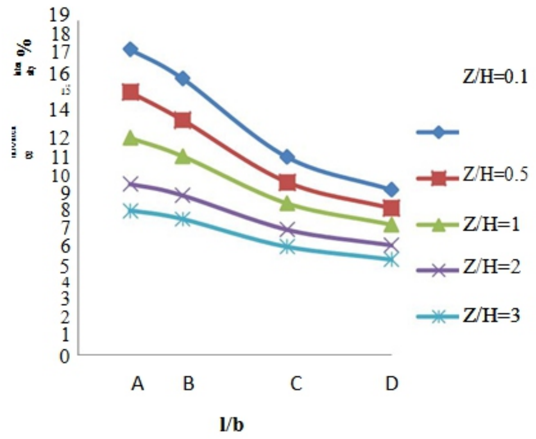

Fig. 14 Turbulence intensity at five successive planes downstream of vortex generator as f(length/width) of the vortex generator

The intensity of turbulence of double pair of vortex generators is little higher than the intensity of turbulence of single pair of vortex generators is shown in Fig. 12.

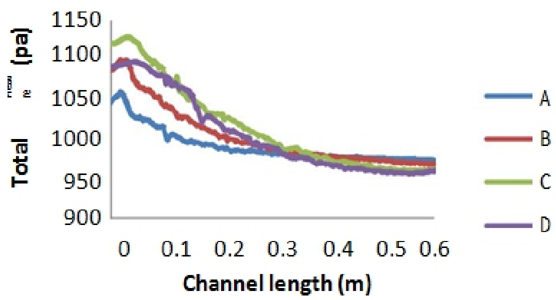

Fig. 15 Total pressure at the centerline of the channel as a function of channel length

The total pressure values are taken at the centerline of the channel are shown in Fig.13. The pressure drop is calculated by taking the difference between the total pressure at location z/h=0.1 upstream of the vortex generator and the total pressure at location z/h=3 downstream of the vortex generator. From the plot, the pressure drop of version A vortex generator is much less than the other geometries, namely version B, C and D is similar to the single pair of vortex generators.

CONCLUSION:

A comprehensive investigation has been carried out delta-wing type vortex generators with the aim of increasing the mixing characteristics in the combustor.

This investigation produced an optimum vortex generator geometry, which produces the maximum turbulences at the minimum pressure drop with no recirculation zones. In addition to the optimization of the vortex generator geometry, the version A has low pressure drop than the other geometries namely, version B, C and D in both arrangement. In single pair of vortex generators, version A has no recirculation zones as compared to the other geometries, namely version B, C and D and in Double pair of vortex generators, version D has no recirculation zones as compared to the other geometries, namely version A, B and C.

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